14 ug/L based on a child c chronic exposure

Stephanie: does ADEC prescribe guidance for child-only for noncancer GW as opposed to age-averaged?

3. Provisional Peer Reviewed Toxicity Value Scenario

3.1 Exposure Assessment

EPA R10 See childrisk Check F drive

ARCADIS conducted an HHRA to evaluate the potential for human health risk from exposure to site-related constituents, following protocols presented in the June 8, 2000 ADEC Risk Assessment Procedures Manual that are adopted into regulation in 18 AAC 75. The primary ADEC references for this Revised Draft Final HHRA include the Draft Risk Assessment Procedures Manual (ADEC 2010a and 2011d), Cleanup Levels Guidance (ADEC 2008a), Cumulative Risk Guidance (ADEC 2008b), and 18 AAC 75 Oil and Other Hazardous Substances Pollution Control guidance (ADEC 2008c). Other references used include RAGS (USEPA 1989, 1991, 2001, 2004a and 2009a), Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (USEPA 2002a), Vapor Intrusion Pathway: A Practical Guide (ITRC 2007a) and Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios (ITRC 2007b).

3.1.1 Human Health Conceptual Site Models

Two preliminary human health CSMs (one onsite CSM and one offsite CSM) were prepared and submitted to the ADEC with the Site Characterization Work Plan (Barr 2010b). After this submittal, a substantial amount of additional site assessment data was collected and in April 2011 the updated CSMs were submitted to the ADEC to reflect the enhanced understanding of site conditions. In the RAWP submitted to ADEC in December 2011 (ARCADIS 2011a), the CSMs were further refined to better reflect existing site conditions. The updated CSMs were developed following the Human Health Conceptual Site Model Graphic and Scoping Forms and the Policy Guidance on Developing Conceptual Site Models (ADEC 2010b and 2010c, respectively). Due to the significant difference in COPC occurrence onsite (petroleum hydrocarbon constituents and sulfolane) versus offsite (sulfolane only), two human health CSM graphic forms (Figures 3-1 and 3-2) were prepared and updated to more clearly portray and distinguish potential exposure pathways for possible on- and offsite receptors.

thorough job of looking at indirect exp pathways

This section describes the CSMs submitted to the ADEC in December 2011 and revisions to the offsite CSM based on ADEC comments discussed during the meeting held on January 24, 2012. Human health CSMs for on- and offsite locations are presented on Figures 3-1 and 3-2, respectively, and are discussed in the following subsections.

3.1.1.1 Potential Sources

During site operations, various materials associated with the crude oil refining process have been released in operating areas of the site, including the crude oil processing units, extraction unit, loading racks, wastewater lagoons, sumps and drain systems. In addition, spills and/or leaks to surface soil from ASTs, pumps and associated piping during routine operations constitute potential sources of petroleum

followed a combination of EPA and ADEC guidance

~~adjustments to~~ standard exposure assumptions appear to have been made on a reasonable mix of standard and site-specific values.

constituents at the site. Petroleum hydrocarbons have also been detected in historical groundwater samples collected from onsite monitoring wells.

Onsite impacted environmental media may include surface (0 to 2 feet bgs) and subsurface (to a depth of 15 feet bgs, the maximum depth at which human exposure is likely to occur) soil, groundwater, indoor and outdoor air, surface water, sediment and biota. Offsite impacted media may include groundwater, surface water, sediment, wild food (such as fish) and homegrown produce.

3.1.1.2 Potential Fate and Transport Mechanisms

As described in Section 3.1.1, the primary sources of COPCs are spills and releases to soil and groundwater during facility operations. COPCs may be retained in site soils or subject to constituent fate and transport mechanisms at the site. Fate and transport mechanisms may include soil sorption; biodegradation; wind erosion and transport; migration to groundwater; advective/dispersive transport in groundwater, on or offsite; and volatilization into soil gas, outdoor air or indoor air.

Potential current and future onsite receptors may be directly exposed to COPCs in surface and subsurface soil via incidental ingestion, dermal contact and inhalation of dust particles in air. In addition, COPCs adhered onto dust particles may migrate from exposed surface or subsurface soil to outdoor air and be breathed by potential offsite receptors. When bound to surface soils, compounds sorbed to soil particles may be subject to wind erosion and windblown transport in outdoor air. Due to the nature of the site, the majority of operational areas are covered with asphalt pavement or gravel. However, exposed and unpaved areas do exist at the site. Therefore, although limited, windborne particulate transport is possible at the site, and this potential pathway was evaluated during the HHRA.

COPCs may leach from soil to groundwater by percolation or may have been directly released to groundwater. Based on groundwater samples collected from onsite wells, sulfolane is the only COPC that is known to have migrated offsite. Potential direct-contact exposures to COPCs in groundwater (e.g., tapwater ingestion and inhalation of volatiles in water) are not expected to occur for current and future onsite commercial/industrial workers because onsite groundwater is only used for industrial purposes (e.g., fire suppression). However, current and future onsite outdoor commercial/industrial receptors may be exposed to COPCs in groundwater by dermal contact while extinguishing fires, if they occur. In addition, due to the relatively shallow average depth to groundwater onsite (historically from 8 to 10 feet bgs), current and future onsite construction/trench workers may be exposed by incidental ingestion of and dermal contact with COPCs in groundwater that has pooled in excavated trenches.

The city provides municipal water for drinking and other potable uses at the site. Current onsite receptors consume drinking water from a municipal source and are expected to consume drinking water from this source in the future. Current and future offsite receptors may be exposed to sulfolane in groundwater that has migrated from the site to wells used for tapwater. In addition, groundwater may be used offsite to irrigate homegrown produce. Sulfolane in groundwater may be taken up by homegrown produce and consumed by offsite residents.

Onsite surface water consists of water that is stored in two lagoons and two gravel pits. Runoff and erosion from soil to surface water may be transport mechanisms. Groundwater from the site flows offsite in a north-northwesterly direction and groundwater is recharged by surface water from the Tanana River. COPCs in groundwater may eventually flow to offsite surface-water bodies and to sediment, which may be contacted by offsite recreational users. Pore-water data were collected to evaluate the potential for exposure at the groundwater/surface-water interface. Some of the samples used for this HHRA were collected when the adjacent surface-water body was frozen; therefore, the degree of connectivity with the surface water, if any, could not be established.

For this HHRA, potential ingestion of sulfolane in surface water by adult and child recreational users while swimming is considered a potentially complete exposure pathway offsite. The collected pore-water samples likely reflect higher sulfolane concentrations than would be expected in true pore-water samples because of limited surface water to groundwater interchange during frozen conditions. Pore-water samples will generally reflect higher sulfolane concentrations than would be encountered by actual recreational users of the surface water bodies because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water (ADHSS 2010). Accordingly, the data used in the surface-water evaluation in this Revised Draft Final HHRA provide a health-protective assessment of risk to swimmers.

Volatilization is another fate and transport mechanism at the site for lighter petroleum hydrocarbon compounds and other VOCs. VOCs may volatilize from subsurface soil into soil gas, with eventual diffusion and/or advection into outdoor air and/or indoor air in onsite buildings. VOCs may also leach from soil to groundwater, where dissolved-phase VOCs may be transported downgradient both on and offsite. VOCs may volatilize from shallow exposed groundwater in excavations directly into outdoor air. VOCs may volatilize from groundwater into soil gas, with eventual diffusion and/or advection into outdoor air and/or indoor air of on- and/or offsite buildings. VOCs may also be subject to degradation by microorganisms in subsurface soils and groundwater. Heavier petroleum hydrocarbon compounds, such as PAHs, adsorb to solids and do not tend to volatilize. As such, these compounds generally tend to remain in place, where they are subject to aerobic biodegradation by microorganisms. Sulfolane is not expected to volatilize under the conditions observed at the site, as discussed in Section 3.1.1.4.

3.1.1.3 Potential Receptors

Potential human receptors were identified based on current and reasonably foreseeable future land use at the site. A review of current and future land use identified the following potential human receptors at the site.

- **Current and future onsite indoor commercial/industrial workers** were considered to be individuals from 18 to 65 years old. It was assumed that these receptors perform commercial and/or industrial work activities (e.g., office work, laboratory analyses, shipping or warehouse inventory management) indoors onsite, under current or future (redeveloped) land use scenarios. Potential exposures to COPCs in soil are considered to be insignificant for onsite indoor commercial/industrial workers. These potential receptors may be exposed to COPCs in indoor air during a standard 40-hour work week for 25 years, for 250 days per year. Potential inhalation of outdoor air is insignificant. Inhalation of VOCs in indoor air was evaluated following USEPA (2009a) RAGS Part F.

- **Current and future onsite outdoor commercial/industrial workers** were considered to be individuals from 18 to 65 years old. These receptors were assumed to perform commercial and/or industrial work activities (e.g., maintenance work for ASTs or associated piping) outdoors at the site under current or future (redeveloped) land use scenarios. These individuals may occasionally use site groundwater for industrial purposes (e.g., fire suppression). Direct-contact exposures with groundwater are considered insignificant because fires are rare onsite and the exposure period is expected to be short. This exposure pathway was not quantitatively evaluated. These potential receptors may be exposed to COPCs in site media during a standard 40-hour work week for 25 years, for 250 days per year. Following ADEC (2010a) guidance, it was assumed that onsite outdoor workers with an average body weight (BW) of 70 kilograms (kg) are exposed to 100 milligrams per day (mg/day) COPCs in surface soil and that 100 percent of the fraction ingested (FI) is from onsite surface soil.

  FHRA requires all onsite workers to wear long-sleeved shirts, long pants and shoes. Thus, the adult commercial/industrial worker outdoor receptor was assumed to wear a long-sleeved shirt, long pants and shoes, which limits the exposed skin surface to the head and hands. The recommended USEPA (2011a) skin surface area (SSA) exposed to impacted soil for the adult commercial/industrial worker outdoor receptor is 2,230 square centimeters (cm^2), which is the average of the adult male and adult female mean values for head and hands. The USEPA (2004a) recommended weighted soil-to-skin adherence factor (AF) for a commercial/industrial adult worker of 0.2 milligram per square centimeter (mg/cm^2) based on the 50^{th} percentile weighted AF for utility workers (i.e., the activity determined to represent a high-end contact activity) was used. Potential inhalation of indoor air was considered insignificant for the outdoor commercial/industrial worker. Inhalation of volatile COPCs and dust in outdoor air was evaluated following USEPA (2009a) RAGS Part F.

- **Current and future onsite construction/trench workers** were considered to be individuals from 18 to 65 years old. These receptors were assumed to perform short-term maintenance and emergency repair activities on underground utilities or facility piping at the site. These receptors may be exposed to COPCs in surface and/or subsurface soil during the work day while performing the maintenance and/or repair task. Because the depth to groundwater at the site generally ranges from 8 to 10 feet bgs, construction/trench workers may be exposed to COPCs in groundwater that has pooled in a trench during performance of the maintenance and/or repair task. It was assumed that the same worker will provide maintenance and/or repair tasks.

  Potential construction/trench worker receptors were assumed to be exposed to COPCs in onsite soil (down to a depth of 15 feet bgs) and groundwater for 1 hour each day of a standard 5-day work week, for 125 days, for 1 year. This exposure frequency (EF) is a modification from that proposed in the RAWP (250 days per year). This deviation is justified because most of the utilities at the site are located aboveground and trenching activities typically do not occur during 6 months of each year, when the ground is frozen. It is assumed that soil may be accessible for trenching activities (i.e., not frozen) for 6 months per year.

  Construction/trench workers with an average BW of 70 kg are assumed to be exposed to 330 mg/day (USEPA 2002b) of COPCs in surface and subsurface soil, and 100 percent of the FI is assumed to be from surface and subsurface soil. It was assumed that onsite construction/trench workers incidentally ingest 0.0037 liter per day (L/day) of groundwater pooled in a trench. This rate is based on the mean ingestion rate for wading/splashing presented in the USEPA (2011a) Exposure Factors Handbook (EFH) Table 3-93 (3.7 milliliters per hour * 1 hour per day). This consumption rate is likely to overestimate actual exposure, because dewatering usually occurs at excavation sites where water has pooled in trenches.

  FHRA requires all onsite workers to wear long-sleeved shirts, long pants and shoes. Therefore, the onsite adult construction worker receptor was assumed to wear a long-sleeved shirt, long pants and shoes, and the exposed SSA was limited to the head and hands. The USEPA (2011a) recommended SSA exposed to impacted soil for the adult construction worker receptor is 2,230 cm^2. The USEPA (2002b) recommended weighted soil-to-skin AF for a construction worker of 0.3 mg/cm^2-day was used. Inhalation of volatile COPCs and dust in outdoor air were evaluated following USEPA (2009a) RAGS Part F.

- **Current and future onsite visitors and trespassers.** Occasional visitors or trespassers may also be present onsite. However, the site does not and is not expected to attract trespassers because of the character and location of the site (i.e., an industrial setting with controlled access). Moreover, it is anticipated that a trespasser's exposure at the site would be very infrequent. Onsite visitors are typically adults with limited access across the site. Children rarely visit the site. Thus, potential direct-contact exposures to COPCs in soil and groundwater by current and future onsite trespassers and visitors are insignificant. Potential inhalation of outdoor air is also insignificant. However, assuming the adult visitor is located in an onsite building, inhalation of volatile COPCs in indoor air by this potential receptor was evaluated following USEPA (2009a) RAGS Part F. Current and future onsite adult visitors (18 to 65 years of age) are assumed to be exposed to COPCs in indoor air for 2 hours per day, 12 days per year for 30 years.

- **Current and future offsite residents** were evaluated as infants (0 to 1 year of age), children (0 to 6 years of age) and adults (18 to 65 years of age). HHRAs do not typically focus on infant exposures as a separate receptor group, but infants are included here because the Agency for Toxic Substances and Disease Registry (ATSDR 2011) and the State of Alaska Department of Health and Social Services (ADHSS 2012) have addressed infants as a separate receptor group in their Health Consultations. There is evidence that sulfolane does not present a significant risk for developmental effects and it is not mutagenic, mitigating infant-specific exposure concerns. Resident receptors were assumed to be located downgradient of the site and may be exposed to sulfolane in groundwater that has migrated from the site. No other COPCs associated with site operations are known to be present in offsite groundwater. These potential offsite receptors may ingest sulfolane in groundwater as tapwater. In addition, it was assumed that these potential receptors consume homegrown produce, which may have taken up sulfolane from groundwater. It was assumed that potential resident receptors may be exposed to sulfolane in tapwater for a 1-, 6- and 30-year duration for infants, children and adults, respectively, for 350 days per year.

  Current and future offsite adult, child and infant residents may also inhale dust from the site. Inhalation of dust in outdoor air by these potential receptors was evaluated following USEPA (2009a) RAGS Part F.

  Following ADEC (2010a) guidance, it was assumed that 70 kg adult residents consume 2 L/day of tapwater. Following USEPA (1989) guidance, it was assumed that 15 kg child residents consume 1 L/day of tapwater. Infants were assumed to weigh an average of 6.75 kg (the average of the age-group specific mean values from 0 to 1 year) and to consume 1.05 L/day (the time-weighted average of the *per capita* age-group-specific 95th percentile values from 0 to 1 year) of tapwater based on USEPA (2011a) guidance. The groundwater ingestion exposure parameters for infants likely overestimate potential exposure, because it was assumed that they do not breastfeed and do not consume formula made with distilled water (a typical pediatric guideline for the first several months of life).

  Fractions of homegrown fruit and vegetables ingested, water-to-produce bioconcentration factors and ingestion rates for offsite adult and child residents for the PPRTV scenario are discussed in Section 3.1.3.1.6.

- **Current and future offsite indoor and outdoor commercial/industrial workers** were considered to be individuals from 18 to 65 years old. It was assumed that these potential receptors perform commercial and/or industrial work activities indoors or outdoors at offsite locations under current or future land use scenarios during a standard 40-hour work week for 25 years, for 250 days per year. These receptors may ingest sulfolane in groundwater as tapwater. Following ADEC (2010a) guidance, it was assumed that 70 kg offsite adult commercial/industrial workers consume 2 L/day of tapwater. In addition, they may inhale dust that may have been released onsite via wind erosion. Potential exposures to COPCs in dust were considered to be insignificant for offsite indoor commercial/industrial workers. Inhalation of dust in outdoor air by outdoor commercial/industrial workers was evaluated following USEPA (2009a) RAGS Part F.

- **Current and future offsite recreational users.** Sulfolane may potentially migrate offsite via groundwater to surface water and to sediment in downgradient surface-water bodies. Access to downgradient, offsite surface-water bodies is minimal due to surrounding industrial land use and hazardous physical conditions, and direct contact with surface water and sediment by human receptors is limited. Regardless, for this HHRA, ingestion of surface water by offsite adult and child recreational users while swimming is considered a potentially complete exposure pathway. Recreational user exposure assumptions for the PPRTV scenario are discussed in Section 3.1.3.3.

- **Current and future offsite construction/trench workers** were considered to be individuals from 18 to 65 years old. These receptors were assumed to perform short-term maintenance and emergency repair activities on underground utilities at offsite properties. These potential receptors may be exposed to sulfolane in groundwater that has pooled in a trench during performance of the maintenance and/or repair task. It was assumed that offsite construction/trench workers incidentally ingest 0.0037 L/day of groundwater pooled in a trench. This rate is based on the mean ingestion rate for wading/splashing presented in the USEPA (2011a) EFH Table 3-93 (3.7 milliliters per hour * 1 hour per day). This consumption rate overestimates actual consumption, because dewatering usually occurs at excavation sites where water has pooled in trenches. It was conservatively assumed that the same worker performs multiple maintenance and/or repair tasks. These potential receptors (70 kg for adults) may be exposed to sulfolane in groundwater for 1 hour each day of a standard 5-day work week, for 125 days per year, for 1 year.

3.1.1.4 Exposure Pathway Evaluation

Potential exposure pathways selected for quantitative evaluation are shown in the on- and offsite human health CSMs. An exposure pathway was retained for further evaluation if it was considered potentially complete. Each of the following components must be present in order for an exposure pathway to be considered complete (USEPA 1989):

- Source and/or constituent release mechanism
- Retention or transport medium
- Receptor at a point of potential exposure
- Exposure route at the exposure point.

Complete exposure pathways were evaluated for identified COPCs. Only potential ingestion exposures were quantitatively assessed for sulfolane. Dermal contact and inhalation exposure routes are not significant for sulfolane. The ATSDR (2010 and 2011) Health Consultations support these conclusions. Animal studies have shown that sulfolane is not readily absorbed through human skin because of its low permeability (Brown et al. 1966) and is not expected to pose a significant risk via an inhalation exposure route due to its low volatility (Andersen et al. 1977). Brown et al. (1966) studied the skin and eye irritant and skin sensitizing properties of acute exposures to sulfolane on two animal species. This study concluded that sulfolane did not irritate or sensitize the skins of guinea pigs or rabbits and, undiluted, was only very mildly irritating on the eyes of rabbits.

Andersen et al. (1977) conducted acute and subacute investigations of the inhalation toxicity of sulfolane on four animal species including monkey, dog, guinea pig and rat. A no-observed-effect level for sulfolane of 20 mg/m^3 was reported, and the authors concluded that airborne concentrations of sulfolane as high as those investigated are unlikely to be encountered on any but an emergency basis. Andersen et al. (1977) reported that sulfolane has a relatively low vapor pressure (approximately 0.13 millimeter of mercury at 32 degrees Celsius [°C]) and only unusual conditions would produce an extensive release of aerosolized sulfolane. Andersen et al. (1977) further noted that if sulfolane is handled at room temperature in an area with proper ventilation, it should not be regarded as posing an unusual hazard.

Potentially complete and significant exposure pathways were identified for the following receptors, with the exception that dermal and inhalation exposures to sulfolane are incomplete (as noted above):

- Onsite indoor commercial/industrial worker (current and future):
  - Inhalation of volatile COPC vapors in indoor air from groundwater.
- Onsite outdoor commercial/industrial worker (current and future):
  - Ingestion of, dermal contact with and inhalation (particulates) of COPCs in surface soil.
  - Dermal contact with COPCs in groundwater while extinguishing fires was qualitatively evaluated.
  - Inhalation of volatile COPC vapors in outdoor air volatilized from surface and subsurface soil and groundwater.

- Onsite construction/trench worker (current and future):
  - Ingestion of, dermal contact with and inhalation (particulates) of COPCs in surface and subsurface soil.
  - Inhalation of volatile COPC vapors in trench air from surface and subsurface soil and groundwater.
  - Ingestion of and dermal contact with COPCs in groundwater in excavation trenches.
- Onsite adult visitor (current and future):
  - Inhalation of volatile COPC vapors in indoor air from groundwater.
- Offsite adult, child and infant residents (current and future):
  - Ingestion of sulfolane in groundwater (i.e., tapwater).
  - Ingestion of homegrown produce irrigated with sulfolane-impacted groundwater.
  - Inhalation of fugitive windborne dust from onsite COPCs in surface soil.
- Offsite indoor and outdoor commercial/industrial worker (current and future):
  - Ingestion of sulfolane in groundwater (i.e., tapwater).
  - Inhalation of fugitive windborne dust from onsite COPCs in surface soil (outdoor worker only).
- Offsite construction/trench worker (current and future):
  - Ingestion of sulfolane in groundwater (i.e., in excavation trenches).
- Offsite adult and child recreational users (current and future):
  - Ingestion of sulfolane in surface water (i.e., pore water).

3.1.2 Data Evaluation, Constituent of Potential Concern Selection and Identification of Data Gaps

The proposed methods for data evaluation, identification of data gaps, selection of COPCs and proposed sampling to address data gaps are discussed below. Both maximum and 95% upper confidence limit (95% UCL) on the mean constituent concentrations for groundwater were evaluated.

3.1.2.1 Data Evaluation

The available data that were used include analytical results from soil investigations conducted at the site since 2001. Data from four sets of soil samples were evaluated, including samples collected in March and May 2001, July 2004, October 2010 and October 2011. One soil sample collected in 2010 (O-2 [7.5-9]) was determined to be unusable in a Level four data validation, so this sample was not included in EPC calculations.

Groundwater and surface-water data collected during the last 2 years were also included. SWI provided the soil and groundwater analytical data used in the HHRA in an electronic format. Initially, the data were separated into individual datasets by environmental media, including: onsite groundwater, offsite (downgradient) groundwater, onsite surface soil (0 to 2 feet bgs) and onsite subsurface soil (2 to 15 feet bgs).

The quality of the data is acceptable for risk assessment use. Parameters evaluated in the data quality assessment include spatial and vertical coverage and representativeness of sampling locations, analytical methods and reporting limits used by the laboratories, and data qualifiers applied during data validation. The HHRA relies on validated data supplied by SWI as presented in the Revised Site Characterization Report (Barr 2012). Data collected for this evaluation were collected per ADEC-approved sampling and analysis plans. Consideration was given to the recently developed standard procedure for analyzing sulfolane in groundwater (isotope dilution) and the historical variability between analytical results. The data relied upon in this risk assessment met the following criteria for data usability for risk assessment as recommended in ADEC (2010a) guidance:

- Analytical data sufficient for adequate site characterization were available.
- Data were collected consistent with ADEC and USEPA guidance.
- Sampling and analytical procedures gave accurate constituent-specific concentrations.
- Level two data validation was performed on analytical laboratory data used for this evaluation. Validation reports for the 2011 soil and groundwater data, and for the 2012 pore-water data prepared

by SWI, were included in the Revised Site Characterization Report (Barr 2012). Level four data validation was performed on the 2010 sulfolane in soil analyses.

- Method detection limits and sample quantitation limits were below screening criteria.
- Qualified data were used in the risk assessment; potential bias from qualified data and how it might result in an over or under estimation of risk is discussed in Section 3.5.
- Rejected data were not used for risk assessment purposes.
- For a given well, if all samples were reported as non-detects, then the lowest detection limit associated with any sampling event at that well was used to represent the well.
- If a well had both detected concentrations and reported non-detects for a given COPC, then the non-detect was represented by a value equal to one-half the detection limit associated with that COPC in that sampling event.

Offsite groundwater has been sampled at monitoring wells and private residential wells. At the request of ADEC, the off-site area was delineated into smaller exposure units (EUs) for the purposes of the 95% UCL evaluation. Accordingly, ARCADIS developed three separate exposure units (e.g., Exposure Unit 1 [EU-1], Exposure Unit 2 [EU-2] and Exposure Unit 3 [EU-3]) for statistical evaluation. These EUs were based on estimated sulfolane isocontour lines developed from fourth quarter 2011 groundwater sampling data, and generally reflect spatially contiguous areas that represent certain ranges of concentration and portions of the sulfolane plume in groundwater. Some data points outside of the concentration range are present within each of the defined EUs and are the result of data collected from well screens of varying depths. These data points were included in the analysis, because it is reasonable to assume that any hypothetical exposures to water from drinking water wells within any given unit may also include exposures to groundwater generated at varying depths. The EUs are bounded by the concentration contours of greater than (>) 100 µg/L, >25 µg/L and detectable sulfolane (Figure 3-3). These contour intervals were selected and drawn using the combined offsite well data set and are based on best professional judgment. Guidance presented in the Data Quality Assessment: Statistical Methods for Practitioners (USEPA 2006a) was considered during selection of the off-site groundwater dataset(s). The data from wells within a given EU were used to estimate the 95% UCL on the mean concentration as a health-protective and representative EPC. ProUCL version 4.1 (USEPA 2011b) was used to derive the 95% UCL on the mean of the constituent concentrations.

The utility of the soil and groundwater analytical data identified in the SWI (2000 and 2001) contaminant characterization studies conducted for the site was evaluated for the HHRA. The characterization study conducted at the site in 2001 was performed to collect additional soil and groundwater data to address data gaps from the site investigation conducted in 2000. In general, for both media, the analytical methods used included those for GRO, DRO, RRO, BTEX, selected metals, VOCs, SVOCs and sulfolane (for groundwater only).

3.1.2.2 Constituents of Potential Concern

COPCs have been identified from a list of potential constituents of interest (COIs), such as those that were likely used or spilled at the site. COPCs for each dataset were carried through the HHRA process.

Preliminary lists of COIs and COPCs in soil and groundwater at the site were presented in the Site Characterization and First Quarter 2011 Groundwater Monitoring Report (Barr 2011). The lists were revised in the Addendum (ARCADIS 2011b) based on the ADEC (2011a) Comment Matrix on the site characterization report. The lists of preliminary COIs and COPCs were also presented in the RAWP (ARCADIS 2011a).

As noted in the RAWP (ARCADIS 2011a), the list of COIs was developed according to the following process:

1. FHRA compiled a list of spills based on staff interviews, refinery records and a review of spill records retained by the ADEC.

2. The list of spills was refined by eliminating:

    a. Spills less than 10 gallons.
    b. Spills that were reportedly contained.
    c. Spills that were remediated and had confirmation sampling.

For many spills on the list, the material spilled was specific to one ingredient (e.g., propylene glycol) or was a material with obvious and limited ingredients (e.g., kerosene). However, the individual ingredients (e.g., oily water) of the other materials reportedly spilled were not provided. Refinery specialists such as chemists, wastewater experts and production leads were consulted to apply operational knowledge of the refinery to determine the ingredients that made up this set of materials. By this process, the list of spills was then distilled down to the "ingredients" or the primary constituents that make up the material spilled. This ingredient list was also compared to constituents that had been included in laboratory analyses of facility wastewater. The resulting ingredient list was then used to make up a list of COIs for the site. The COI list also included constituents that were analyzed during previous site characterization studies, regardless of whether they were detected above the practical quantitation limit (PQL). The list of COIs for the site is shown in Table 3-1. Constituents in the ingredient list that were analyzed for but not detected were not removed from this list. If a constituent was previously detected at the site and/or was included in the ingredient list, it was considered a COI.

Table 3-1 indicates if a constituent was previously analyzed in soil or groundwater samples collected at the site. Table 3-1 also indicates if a constituent was included in the ingredient list; the last four columns of the table summarize whether toxicity data are available from the USEPA's Integrated Risk Information System ([IRIS]; USEPA 2012a).

For this Revised Draft Final HHRA, maximum detected concentrations and/or the laboratory reporting limits of COIs in soil and groundwater are compared with ADEC screening levels corresponding to a 1×10^{-6} target excess lifetime cancer risk (ELCR) and 0.1 target hazard quotient (HQ), as shown in Table 3-2a. COI soil concentrations were compared with ADEC screening levels protective of potential migration to groundwater based on a zone with less than 40 inches of annual precipitation, direct-contact exposures and outdoor inhalation (ADEC 2008a [Table B-1 of 18 AAC 75, Method Two]). If ADEC soil screening levels were unavailable, then COI concentrations in soil were compared with USEPA Regional Screening Levels ([RSLs]; USEPA 2011c), adjusted to a target ELCR of 1×10^{-6} (if necessary) and a HQ equal to 0.1, for the applicable exposure pathway. Soil screening levels for GRO, DRO and RRO were from ADEC (2008a) Table B-2 Method Two. COI groundwater concentrations were compared with ADEC groundwater screening levels (ADEC 2008a; Table C). If ADEC groundwater screening levels were unavailable, then COI concentrations were compared with USEPA RSLs (USEPA 2011c) based on tapwater ingestion.

The higher of either the maximum COI concentration detected above the laboratory reporting limit or maximum detection limit was compared with the selected ADEC screening levels. The selected soil screening levels were based on the lesser of the migration to groundwater, $^{1}/_{10}$ the direct contact or $^{1}/_{10}$ the outdoor air screening levels. COIs with concentrations exceeding the selected soil screening level were identified as COPCs. Table 3-2a lists the COPCs identified in soil and groundwater based on ADEC (2010a) COPC selection guidance applied to the COIs identified in Table 3-1.

The preliminary COPCs identified at the site, as presented in Table 3-2a, are COIs that were detected in site media and exceeded ADEC screening levels. COIs not detected in site media but that had practical quantitation limits exceeding ADEC screening levels and COIs identified by the refinery as ingredients that could have been released are also considered COPCs. Arsenic was eliminated as a COPC in groundwater based on published background concentrations for the area of the site (U.S. Geological Survey 2001). However, it was retained as a COPC in soil in the RAWP (ARCADIS 2011a). An evaluation of the 2011 arsenic in soil data was presented in the Revised Site Characterization Report (Barr 2012). Based on this evaluation, it is likely that the presence of detectable arsenic in soil samples collected at the site is attributable to background concentrations. No other metal COIs were eliminated from the list of COPCs based on background concentrations. In accordance with ADEC (2010a) guidance, Table 3-2a has been provided to the ADEC in Microsoft® Excel format.

Table 3-2b summarizes COPCs by environmental media.

3.1.2.3 Data Gaps

Based on a review of the preliminary human health CSMs and available analytical data for environmental samples collected at the site, and discussions held during the June 24, 2011 Risk Assessment Scoping Meeting, four potential risk assessment data gaps were indicated:

- Limited surface soil data were available for the evaluation of potential risks and hazards to onsite human receptors.
- Onsite containment of COPCs other than sulfolane must be supported.
- Possible connection between groundwater at the site and surface water must be determined.
- No soil gas data were available to evaluate onsite vapor intrusion concerns.

3.1.2.4 Sampling Plans to Address Data Gaps

Sampling plans for additional data collection are described in the Addendum (ARCADIS 2011b). With respect to risk assessment data gaps identified in Section 3.1.2.3, the following field activities have been conducted:

- Onsite soil assessment activities, to characterize soil impacts and provide data for risk assessment activities. The soil data collected in 2011 adequately characterized the nature and extent of surface and subsurface impacts for the purposes of this HHRA evaluation. Additional sampling is planned for 2012 to complete characterization for the purposes of a remediation feasibility study. The 2011 soil data were validated and included in this evaluation.
- Additional groundwater sampling, during the third and fourth quarters 2011, confirmed that no other COPCs (except sulfolane) have migrated offsite.

A pore-water investigation was conducted to better characterize sulfolane concentrations in the groundwater/surface-water interface and the potential for surface-water sulfolane impacts. The March 2012 samples were collected when the adjacent surface-water body was frozen; therefore, the degree of connectivity with surface water, if any, could not be established. Therefore, the piezometer samples were likely more representative of groundwater. Because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water (ADHSS 2010), the groundwater collected adjacent to two of the three surface-water bodies in 2012 likely overestimates surface water concentrations at those locations. The data presented in this Revised Draft Final HHRA provide a health-protective estimate of risk to swimmers.

Soil gas data were not collected to evaluate potential vapor intrusion concerns. Instead, onsite groundwater data were used to evaluate the vapor intrusion exposure pathway. All onsite groundwater analytical data collected during the last 2 years (2009 through 2011) were used to predict indoor air concentrations of volatile COPCs and to estimate risks and hazards to current and future onsite indoor commercial workers. The maximum detected groundwater concentration for each COPC was used as the source term for Johnson & Ettinger (J&E) groundwater-to-indoor air modeling (USEPA 2004b) in the maximum exposure scenario. The 95% UCL concentration calculated from the average concentration in each onsite well was used as the source term in the 95% UCL scenario.

3.1.3 Quantification of Exposure

The objective of the exposure assessment was to estimate the type and magnitude of potential receptor exposure to COPCs. Results of the exposure assessment were then combined with constituent-specific toxicity values in the toxicity assessment (see Section 3.2) to characterize potential risks (USEPA 1989).

3.1.3.1 Dose/Intake Equations

Exposures were quantified using standard exposure equations consistent with RAGS (USEPA 1989, 1991, 2004a and 2009a) for the potentially complete exposure pathways identified in Section 3.1.1.4.

The general algorithms presented below were used to estimate the lifetime average daily dose (LADD) for carcinogenic compounds and the average daily dose (ADD) for noncarcinogenic COPCs for direct-contact pathways (i.e., ingestion and dermal contact) by combining environmental media concentrations with the receptor-specific exposure parameters that constitute "intake factors." Both the ADD and the LADD are in units of milligrams per kilogram per day (mg/kg-day) (USEPA 1989). For inhalation exposure pathways, exposure was estimated as an average exposure concentration (AEC) for noncarcinogenic COPCs or lifetime average exposure concentration (LAEC) for carcinogenic COPCs. Both the AEC and the LAEC are in units of milligrams per cubic meter (mg/m^3) (USEPA 2009a).

The dose equations and parameter descriptions used are provided in the following subsections.

3.1.3.1.1 Incidental Ingestion of Soil

The doses of COPCs associated with incidental ingestion of soil were calculated as follows:

$$\text{Dose} = \frac{EPC_s * IR_s * FI * EF * ED * CF}{BW * AT} * RAF$$

Where:

Dose = ADD or LADD (mg/kg-day)

EPC_s = EPC in soil (milligrams per kilogram [mg/kg])

IR_s = soil ingestion rate (milligrams soil per day)

FI = fraction ingested (unitless)

EF = exposure frequency (days per year)

ED = exposure duration (years)

CF = conversion factor (1×10^{-6} kilograms per milligram [kg/mg])

BW = body weight (kg)

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

RAF = relative absorption factor (unitless), assumed to equal 1

The USEPA (1989) defines FI as a "pathway-specific" value that should be applied to consider constituent location and population activity patterns. FI accounts for the fraction of the site covered with asphalt or vegetation, which reduces potential exposure. Following the ADEC's (2010a) guidance, an FI of 1 was assumed for the current and future onsite outdoor commercial/industrial worker and future onsite construction/trench worker, despite the fact that much of the site is covered with asphalt and buildings.

3.1.3.1.2 Dermal Contact with Soil

Absorbed doses of constituents associated with dermal contact with soil were calculated as follows:

$$\text{Dose} = \frac{EPC_s * SSA_s * AF * FC * ABS_d * EV_s * EF * ED * CF}{BW * AT}$$

Where:

Dose = ADD or LADD (mg/kg-day)

EPC_s = EPC in soil (mg/kg)

SSA_s = SSA available for contact (cm^2/event)

AF = soil-to-skin adherence factor (mg/cm^2-event)

FC = fraction in contact with soil (unitless)

ABS_d = dermal absorption factor (unitless)

EV_s = event frequency (soil) (events/day), assumed to be 1 per day unless otherwise noted

EF = exposure frequency (days/year)

ED = exposure duration (years)

CF = conversion factor ($1x10^{-6}$ kg/mg)

BW = body weight (kg)

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

Constituent-specific dermal parameters, such as SSA_s, AF and ABS_d were provided from USEPA (2004a) RAGS Part E. ABS_d are presented in Table 3-13.

Similar to FI for the soil ingestion pathway, FC was added to the dermal contact equation to account for the fraction of the site covered with asphalt or vegetation, which reduces potential exposure. Following the ADEC's (2010a) guidance, an FC of 1 was assumed for the current and future onsite commercial/industrial worker and future onsite construction/trench worker.

3.1.3.1.3 Ingestion of Groundwater

The doses of COPCs associated with ingestion of groundwater were calculated as follows:

$$\text{Dose} = \frac{EPC_w * IR_w * EF * ED}{}$$

BW * AT

Where:

Dose = ADD or LADD (mg/kg-day)

EPC_w = EPC in water (milligrams per liter [mg/L])

IR_w = water ingestion rate (liters water/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight (kg)

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

3.1.3.1.4 Dermal Contact with Groundwater

Absorbed doses of constituents associated with dermal contact with groundwater were calculated as follows:

$$\text{Dose} = \frac{DA_{event} * SSA_w * EV_w * EF * ED}{BW * AT}$$

Where for organics ($t_{event} \leq t^*$):

$$DA_{event} = 2 * FA * K_p * EPC_w * CF * \sqrt{\frac{6 * \tau_{event} * t_{event}}{\pi}}$$

Where for organics ($t_{event} > t^*$):

$$DA_{event} = FA * K_p * EPC_w * CF * \left[\left(\frac{t_{event}}{(1+B)}\right) + \left(2\tau_{event}\left[\frac{1+3B+3B^2}{(1+B)^2}\right]\right)\right]$$

Where for inorganics:

$$DA_{event} = K_p * EPC_w * CF * t_{event}$$

Dose = ADD or LADD (mg/kg-day)

DA_{event} = dose per event (mg/cm^2-event)

SSA_w = SSA available for contact with water (cm^2/event)

EV_w = event frequency (water) (events/day), assumed to be 1 per day unless otherwise noted

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight (kg)

t* = time to reach steady state (hours), equivalent to 2.4 x τ_{event}

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

FA = fraction absorbed (unitless)

K_p = permeability coefficient (centimeter/hour)

EPC_w = EPC in water (mg/L)

CF = conversion factor ($1x10^{-3}$ liters per cubic centimeter)

τ_{event} = lag time per event (hours/event)

B = permeability ratio (unitless)

t_{event} = event duration (hours/event)

3.1.3.1.5 Inhalation of Outdoor or Indoor Air

Exposure concentrations associated with the inhalation of vapors or particulates in outdoor or indoor air are calculated using USEPA (2009a) RAGS Part F methodology as follows:

$$\text{AEC or LAEC} = \frac{EPC_a * EF * ED * ET}{AT}$$

Where:

AEC or LAEC = average or lifetime exposure concentration in air (micrograms per cubic meter [$\mu g/m^3$])

EPC_a = EPC in outdoor or indoor air ($\mu g/m^3$)

EF = exposure frequency (days/year)

ED = exposure duration (years)

ET = exposure time (hours/day)

AT = averaging time (hours), for carcinogens is equal to 70 years * 365 days per year * 24 hours per day, and for noncarcinogens AT is equal to ED (in years) * 365 days per year * 24 hours per day

3.1.3.1.6 Ingestion of Homegrown Produce

Groundwater from the site may be used to irrigate locally grown crops, creating the potential for sulfolane to be taken up into plants that are then consumed by humans. In the few studies that have been conducted on the topic of uptake in plants, sulfolane has been demonstrated to be taken up into plants as the result of the constituent's high miscibility with water. Sulfolane is carried, along with water, through the roots, into the xylem and ultimately into the leaves of the plants. When water is lost through the leaves due to evapotranspiration, the sulfolane, due to its low volatility, tends to remain in the leaves where it may accumulate. Based on this information, it is assumed that if sulfolane is taken up by plants, it would predominantly be present in the leaves rather than in the roots or fruit.

This assumption is corroborated by the Final Results of the North Pole Garden Sampling Project (ADEC 2011b), which demonstrated that concentrations in roots were substantially lower than those in the stems and leaves. In the ADEC (2011b) study, which was led by ADHSS, 27 types of plant parts from multiple gardens irrigated with sulfolane-containing groundwater were collected from July to September 2010. Approximately one-half of the plant samples were reported as not detected, but 14 of the plant types tested were confirmed to contain sulfolane, primarily in the leaves and stems. Using data from the Final Results of the North Pole Garden Sampling Project (ADEC 2011b), the ADHSS evaluated the potential for risk to consumers of vegetables irrigated with sulfolane-containing water and concluded that sulfolane levels in the plants were low and not likely to cause any adverse health effects. However, because of the limited number of gardens sampled and the fact that the data were collected during only one growing season, the results of the investigation were considered preliminary and the exposure pathway was further evaluated in this assessment.

Following USEPA (2005) guidance, bioaccumulation of sulfolane in locally grown crops was evaluated using a biotransfer factor to estimate concentrations in plant tissues based on groundwater concentrations. There are no accepted values developed for sulfolane, but there is evidence to suggest that the uptake of sulfolane does not follow standard models based on partitioning coefficients (e.g., K_{ow}); therefore, an appropriate surrogate was not identified. Given the lack of constituent-specific information available in the literature, the ADEC has requested the use of a factor of 1. Use of this value assumes that the concentration of sulfolane in the edible portions of the plant tissues is equivalent to the concentration of sulfolane in groundwater.

After estimating the EPC, the doses of sulfolane associated with resident ingestion of homegrown fruits and vegetables were calculated using the following equation:

$$\text{Dose} = \frac{EPC_p * (IRP_{fr} + IRP_{vg}) * FI * EF * ED * CF}{BW * AT}$$

Where:

Dose = ADD (mg/kg-day)

EPC_p = EPC in produce (mg/kg) = EPC_w * BCF

Where:

EPC_w = EPC in water (mg/L)

BCF = water-to-produce bioconcentration factor (unitless)

IRP_{fr} = fruit ingestion rate (mg/day)

IRP_{vg} = vegetable ingestion rate (mg/day)

FI = fraction ingested (unitless)

EF = exposure frequency (days/year)

ED = exposure duration (years)

CF = conversion factor ($1x10^{-6}$ kg/mg)

BW = body weight (kg)

AT = for the noncarcinogen sulfolane is equal to ED * 365 days per year

The ADEC requested use of adult resident fruit and vegetable ingestion rates of 259,000 and 413,000 mg/day, respectively; child resident fruit and vegetable ingestion rates of 223,500 and 201,000 mg/day, respectively; and infant resident fruit and vegetable ingestion rates of 155,250 and 109,350 mg/day, respectively, based on 95th percentile *per capita* intakes presented in the USEPA (2011a) EFH Table 9-3. The intakes rates presented in the EFH were multiplied by receptor-specific BW (for example, adult fruit ingestion rate was calculated by 3.7 grams per kilogram per day * 70 kg * 1,000 milligrams per gram = 259,000 mg/day). These calculations translate into the assumption that infants will consume approximately 6 ounces of fruits and 4 ounces of vegetables a day; children will consume approximately 8 ounces of fruits and 7 ounces of vegetables a day; and adults will consume approximately 9 ounces of fruits and 15 ounces of vegetables a day. The risk assessment assumes that during their first year of life, infants will ingest approximately 228 pounds of homegrown fruits and vegetables. For children and adults, the assumption is approximately 342 and 548 pounds per year, respectively.

A fraction of 25 percent (i.e., an FI equal to 0.25) consumption of homegrown fruits and vegetables, for offsite residents is used in the exposure assessment. This represents a 3-month growing season.

3.1.3.1.7 Ingestion of Surface Water

The doses of sulfolane associated with ingestion of surface water while swimming were calculated as follows:

$$\text{Dose} = \frac{EPC_w * ET * EF * ED * CR_w}{BW * AT}$$

Where:

Dose = ADD (mg/kg-day)

EPC_w = EPC in water (mg/L)

ET = exposure time (hours per day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

CR_w = contact rate of surface water (liters/hour)

BW = body weight (kg)

AT = for the noncarcinogen sulfolane is equal to ED * 365 days per year

For the PPRTV Scenario, as shown in Table 3-12, the offsite adult and child recreational user surface-water ingestion rates of 0.071 and 0.12 liter/hour, respectively, were based on recommended upper percentile values for swimmers presented in the USEPA (2011a) EFH Table 3-5 representing the maximum ingestion rate for adults and the 97th percentile ingestion rate for children age 18 and under. Adult and child (1 to 6 years of age) recreational users were assumed to swim for 30 and 6 years, respectively, for 60 days per year for 1 hour per day.

3.1.3.2 Exposure Point Concentrations

Per ADEC (2010a) guidance, "the exposure point concentration is used to assess risk and should be estimated using a 95% UCL on the mean of the contaminant concentrations." The EPC represents the average concentration of a COPC in an environmental medium that is potentially contacted by a receptor during the exposure period (USEPA 1989). The USEPA (1989) also recommends the use of the 95% UCL as a conservative estimate of the EPC, because it represents the average concentration for which we have 95 percent confidence that the true mean concentration has not been exceeded. Unless there is site-specific evidence to the contrary, an individual receptor is assumed to be equally exposed to media within all portions of the EU during the time of the risk assessment (USEPA 2002c). For this HHRA ADEC has also requested evaluation of maximum COPC concentrations in groundwater as EPCs in the PPRTV Scenario. Note that the ADEC Draft Risk Assessment Procedures Manual was updated during preparation of this HHRA (ADEC 2011c). The updated manual includes guidance on the use of maximum groundwater concentrations for EPCs.

EPCs are estimated separately for each medium. Consistent with USEPA (2006b, 2007) guidance, surface soil, subsurface soil and groundwater EPCs were estimated using the 95% UCL of the mean for datasets with at least eight samples and at least five detected values. For this HHRA, a "dataset" was considered the aggregate of samples for one COPC, for one pathway, within a particular EU (onsite or offsite). Calculation of a 95% UCL depends on the distribution of the dataset and variability in the data. To assess statistical validity, data evaluation, distribution testing and 95% UCL calculations were performed using the USEPA's ProUCL version 4.1 (http://www.epa.gov/osp/hstl/tsc/software.htm) and according to the recommendations provided in the associated technical documentation (USEPA 2006, 2007, 2011b). Analytical data used for the HHRA are provided in Appendix A and ProUCL output files are included in Appendix B. For datasets with fewer than eight samples or fewer than five detected values, the EPC was the maximum detected concentration. Soil and groundwater datasets for most COPCs have more than eight samples each.

To combine data collected from monitoring wells and private residential wells, individual well means were calculated. The following methods were used to normalize the groundwater data in a manner that provides equal representation between wells with different numbers of observations:

- For a given well, if all samples were reported as non-detects, then the lowest detection limit associated with any sampling event at that well was used to represent the well.

- If a well had both detected concentrations and reported non-detects for a given COPC, then any non-detect was represented as one-half the detection limit associated with that sampling event for that COPC.

With the individual well means calculated as described above, ProUCL was used to estimate the 95% UCL of the mean of sulfolane across all wells in an EU (Figure 3-3). EU-1 represents approximate sulfolane concentrations in groundwater of ≥100 µg/L, EU-2 where detected sulfolane concentrations range from ≥25 to 99.9 µg/L, and EU-3 where sulfolane concentrations ranged from not detected above the laboratory reporting limit to 24.9 µg/L. Given the sizable area of each EU, some results included in the data analyses are different from others in each EU. For example, some non-detect results occur in EU-1 and EU-3. These values are primarily attributable to groundwater samples collected from variable screen depths. It is reasonable to assume that groundwater extracted from a variety of screen lengths may be ingested by potential receptors that might use groundwater as drinking water. Therefore, these data points were included in the EPC calculations for each EU. Non-detect observations for the COPCs in soil and groundwater were addressed using the methods described above.

In addition, per ADEC (2010a) guidance for duplicate samples, the highest detected value from the primary and duplicate samples was used to represent that sample result. For any COPC, if the 95% UCL COPC of the mean concentration exceeded the maximum detected concentration, then the maximum detected concentration was the EPC. Summary statistics for the COPCs are presented in the risk characterization, including detection frequency, number of samples, minimum and maximum detected concentrations, and calculated 95% UCL concentrations.

EPCs were estimated separately for each medium. Tables 3-3 through 3-10 present area-wide summary statistics and EPCs for COPCs as follows:

- Surface soil (0 to 2 feet bgs; see Table 3-3 for 95% UCL COPC concentrations)
- Subsurface soil (0 to 15 feet bgs; see Table 3-4a for maximum COPC concentrations and Table 3-4b for 95% UCL COPC concentrations)
- Onsite groundwater (see Table 3-5a for maximum COPC concentrations and Table 3-5b for 95% UCL COPC concentrations)
- Offsite groundwater in all wells (see Table 3-6 for maximum sulfolane concentration)
- Offsite groundwater in EU-1 (see Table 3-7 for 95% UCL sulfolane concentration)
- Offsite groundwater in EU-2 (see Table 3-8a for maximum sulfolane concentration and Table 3-8b for 95% UCL sulfolane concentration)
- Offsite groundwater in EU-3 (see Table 3-9a for maximum sulfolane concentration and Table 3-9b for 95% UCL sulfolane concentration)
- Offsite surface water (see Table 3-10 for maximum sulfolane concentration estimated from pore water).

Soil, groundwater, outdoor air, indoor air, homegrown produce and surface-water EPCs are further discussed below.

3.1.3.2.1 Soil Exposure Point Concentrations

Onsite receptors may potentially contact surface soil or a combination of surface and subsurface soil. According to ADEC guidance 18 AAC 75.340(j)(2), "human exposure from ingestion, direct contact or inhalation of a volatile substance must be attained in the surface soil and the subsurface soil to a depth of at least 15 feet, unless an institutional control or site conditions prevent human exposure to the subsurface" (ADEC 2008c). Currently and in the future, FHRA will have institutional controls in place (i.e., permits) that provide worker protection (i.e., appropriate personal protective equipment) in the event of planned excavation of onsite soil. For this HHRA, two soil EPCs are calculated for each COPC. Surface soil is considered to occur from 0 to 2 feet bgs (Table 3-3) and subsurface soil is considered to occur from 0 to 15 feet bgs (Tables 3-4a and 3-4b). EPCs for soil were calculated using the 95% UCL on the mean of the dataset for surface soil exposures, or the maximum detected COPC concentrations for surface and subsurface soil exposures (relevant to potential onsite construction/trench workers).

3.1.3.2.2 Surface Soil Exposure Point Concentrations

For this HHRA, it is presumed that onsite commercial/industrial workers may potentially contact surface soil onsite that is not covered with pavement or vegetation. Therefore, surface soil EPCs were calculated and used to evaluate potential exposure by onsite commercial/industrial workers, using analytical data from the surface soil dataset in uncovered portions of the site (i.e., soil samples collected from ground surface to 2 feet bgs). The 95% UCL of the mean concentrations of COPCs in surface soil collected from 0 to 2 feet bgs were used to evaluate:

- Direct-contact exposure pathways to onsite outdoor commercial/industrial workers
- Potential inhalation of fugitive windborne dust from onsite surface soil by onsite outdoor commercial/ industrial workers, offsite residents and offsite outdoor commercial/industrial workers.

3.1.3.2.3 Surface and Subsurface Soil Exposure Point Concentrations

The 95% UCL of the mean concentrations of surface soil collected from 0 to 2 feet bgs were used to evaluate direct-contact exposure pathways to onsite outdoor commercial/industrial workers, and potential inhalation of fugitive windborne dust from onsite soil by onsite and offsite outdoor commercial/industrial workers. The onsite construction/trench worker may be directly exposed to surface and subsurface soil during excavation activities. Therefore, EPCs for evaluating exposure by the onsite construction/trench worker were generated using analytical data from the combined surface and subsurface soil dataset (i.e., soil samples collected from ground surface to as deep as 15 feet bgs). The maximum detected concentrations in the combined surface and subsurface soil sample dataset were used to estimate surface and subsurface soil EPCs for direct-contact pathways for the onsite construction/trench worker because that exposure may be localized rather than averaged over the entire site. In addition, in accordance with ADEC guidance (2010a), surface and subsurface soil EPCs based on the 95% UCLs were also used to evaluate potential exposures by the construction/trench worker.

3.1.3.2.4 Groundwater Exposure Point Concentrations

For COPCs in groundwater, COPC EPCs were distinguished for both on- and offsite potential exposures as described in the following sections.

3.1.3.2.4.1 Onsite Groundwater Exposure Point Concentrations

Groundwater EPCs were used to estimate direct-contact exposure (i.e., dermal contact) by the onsite outdoor worker and incidental ingestion and dermal contact by onsite construction/trench workers during excavation activities. Groundwater COPC EPCs were estimated using the last 2 years of data (i.e., 2009 to 2011) collected from onsite groundwater monitoring wells. In addition to evaluating the potential exposures to COPCs in groundwater over an EU using 95% UCL concentrations, the ADEC also requested that groundwater EPCs be calculated using the maximum detected concentration during the last 2 years of groundwater monitoring (see Tables 3-5a and 3-5b).

3.1.3.2.4.2 Offsite Groundwater Exposure Point Concentrations

Offsite sulfolane groundwater EPCs were used to estimate direct-contact exposure (i.e., incidental ingestion) by offsite construction/trench workers during excavation activities and to estimate direct-contact exposure (i.e., ingestion) by offsite residents and commercial/industrial receptors. In addition to evaluating the potential exposures to sulfolane in groundwater using a 95% UCL concentration for each of the EUs depicted on Figure 3-3, the ADEC also requested risk calculations using the maximum detected sulfolane concentration during the last 2 years of groundwater monitoring (i.e., 2009 to 2011), applied to the entire offsite area. EPCs were derived for each offsite EU identified on Figure 3-3 including:

- All offsite wells (Table 3-6), evaluated using the maximum offsite concentration as the EPC
- EU-1 (Table 3-7), evaluated using the 95% UCL concentration in offsite wells in EU-1 (the maximum concentration located in EU-1 is the same as the off-site maximum concentration, as shown in Table 3-6)
- EU-2 (Table 3-8a for maximum concentrations and Table 3-8b for 95% UCL concentrations)
- EU-3 (Table 3-9a for maximum concentrations and Table 3-9b for 95% UCL concentrations).

In summary, the maximum detected concentrations of sulfolane in offsite groundwater from EU-1, EU-2 and EU-3 were used to estimate risks and hazards for relevant receptors for the PPRTV Scenario. In addition, for each EU, EPCs based on the 95% UCL were also used to estimate risks and hazards for relevant receptors at each of the offsite groundwater offsite EUs (EU-1, EU-2 and EU-3), per USEPA (1989) guidance, professional judgment, and the RAWP (ARCADIS 2011).

3.1.3.2.5 Outdoor Air Exposure Point Concentrations

In accordance with the USEPA (1989), exposure to constituents in outdoor air was evaluated as exposure to fugitive dust emissions (for non-VOCs, from soil only) or volatile emissions (for VOCs, from soil or groundwater). The USEPA (2002b) recommendations for media transfer factors to evaluate these exposures are described below.

3.1.3.2.5.1 Estimating Outdoor Air Exposure Point Concentrations from Soil Concentrations

A particulate emission factor (PEF) for non-volatile COPCs was used to estimate EPCs in outdoor air from soil. The industrial PEF (1.36×10^9 cubic meters per kilogram [m^3/kg]) obtained from the Supplemental Guidance for Developing Soil Screening Levels for Contaminated Sites (USEPA 2002b) was used to estimate outdoor air EPCs of non-volatile COPCs for onsite outdoor commercial/industrial workers and construction/trench workers potentially exposed to particulate emissions from soil.

A volatilization factor (VF) for VOCs was used to estimate EPCs of volatile COPCs in outdoor air from soil (VF_{soil}). Outdoor air EPCs were estimated for the onsite outdoor commercial/industrial worker and onsite construction/trench worker using the EPC for the combined surface and subsurface soil dataset. Constituent-specific VFs_{soil} were obtained from the USEPA (2011c) RSL spreadsheets, where they exist, to estimate outdoor air EPCs of volatile COPCs for onsite outdoor commercial/industrial workers and construction/trench workers potentially exposed to volatile COPCs emanating from surface and subsurface soil. For volatile COPCs not listed in the USEPA's RSL table, VFs were derived according to USEPA guidance (USEPA 2002b). Table 3-11 presents the VFs_{soil} that were used to calculate VFs_{soil} if they were not available on the RSL spreadsheets.

The following equation was used to calculate outdoor air EPCs from soil EPCs using either a PEF or VF_{soil}:

$$EPC_a = \frac{EPC_s}{PEF\ or\ VF_{soil}}$$

Where:

EPC_a = EPC in air (mg/m^3)

EPC_s = EPC in soil (mg/kg)

PEF = particulate emission factor (m^3/kg)

VF_{soil} = volatilization factor (soil) (m^3/kg)

3.1.3.2.5.2 Estimating Outdoor Air Exposure Point Concentrations from Groundwater Concentrations

Construction workers (i.e., trench workers) may also be exposed to VOCs released from shallow groundwater that may pool in a trench and volatilize to trench air. Groundwater occurs as shallow as 8 feet bgs in portions of the site. To estimate the potential concentrations of COPCs that could volatilize from groundwater to trench air, volatilization factors (VF_{gw}) obtained from the Virginia Department of Environmental Quality (2012) were used to estimate trench air EPCs from groundwater. The trench air EPCs were used to evaluate potential exposures by on and offsite construction/trench workers potentially exposed to volatile COPCs emanating directly from shallow groundwater in an excavation trench. The equation for using VF_{gw} to calculate trench air EPCs from groundwater EPCs is as follows:

$$EPC_a = EPC_{gw} \cdot VF_{gw}$$

Where:

EPC_a = EPC in trench air (mg/m^3)

EPC_{gw} = EPC in groundwater (mg/L) (as 95% UCL and as maximum EPC; see Section 3.1.3.2.4 for discussion about on and offsite groundwater EPCs)

VF_{gw} = volatilization factor (groundwater) (liter per cubic meter)

For onsite exposures, the trench air EPCs are presented in Table 3-5a (maximum EPC) and Table 3-5b (95% UCL EPC).

As discussed in Section 3.1.1, onsite construction/trench workers may potentially be exposed to vapors emanating from soil during trench excavation. Therefore, potential exposures to volatile EPCs in trench air from both soil and shallow groundwater sources, as well as COPCs as fugitive dust from soil were estimated for onsite construction/trench workers. For offsite construction/trench workers, sulfolane in trench air from offsite groundwater is the only potential exposure onsite.

3.1.3.2.6 Indoor Air Exposure Point Concentrations

The Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (USEPA 2002a), Vapor Intrusion Pathway: A Practical Guide (ITRC 2007a) and Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios (ITRC 2007b) were used to assess vapor intrusion. The J&E model was used to estimate indoor air concentrations resulting from intrusion of vapors from sub-slab soil gas into onsite buildings. The J&E model is a one-dimensional, screening-level model used to evaluate subsurface vapor intrusion into buildings. It incorporates both convective and diffusive mechanisms to estimate the transport of constituent vapors emanating from soil gas into indoor spaces located directly above the source (J&E 1991, USEPA 2004b). When estimating the concentration of COPC vapors in indoor air, the J&E model assumes the following:

- Constant, infinite source of constituents (e.g., in groundwater or soil gas)
- Steady-state diffusion through the unsaturated zone
- Convective and diffusive transport through the basement floor or slab
- Complete mixing within the building, estimated using an air exchange rate.

Due to the uncertainties associated with partitioning from soil to soil gas, ITRC (2007b) does not recommend using soil data as a source of COPCs to evaluate potential vapor intrusion. Therefore, source concentrations were estimated using the groundwater data as discussed in Section 2.6.2. Source concentrations for the model consisted of the groundwater EPCs based on maximum detected COPC concentrations in groundwater as well as the 95% UCL of the mean groundwater concentrations (see Section 3.1.3.2.4). Site-specific parameters, such as soil type and average soil temperature, were used in the J&E model where available. The top 3 to 5 feet of soil was assumed to be sand. Geotechnical data show that this depth interval is silty sand. An average soil temperature of 5 °C was used. The remaining parameter values, including constituent-specific parameter values, were estimated using the default values provided by the USEPA (2004b) in the User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings and the associated model spreadsheets. Appendix C presents the results of the USEPA's J&E-based model to predict indoor air COPC concentrations from COPC concentrations in onsite groundwater. For onsite exposures, the indoor air EPCs are presented in Table 3-5a (maximum EPC) and Table 3-5b (95% UCL EPC).

3.1.3.2.7 Homegrown Produce Exposure Point Concentrations

Residents who consume homegrown produce that has been irrigated with offsite groundwater were evaluated. Homegrown produce EPCs were calculated using bioconcentration factors (BCFs) applied to offsite groundwater EPCs (Tables 3-6 through 3-9b). The Final Results of the North Pole Garden Sampling Project (ADEC 2011b) showed that sulfolane was taken up into garden plants at concentrations below adult risk-based screening criterion developed by the ADHSS. However, a BCF equal to 1 was used to predict uptake of sulfolane into both aboveground and belowground vegetables (as described in Section 3.1.3.1.6).

3.1.3.2.8 Surface-Water Exposure Point Concentrations

Recreational users who ingest surface water that has migrated from groundwater beneath the site were evaluated. The maximum detected concentration of sulfolane collected during the 2012 field season from adjacent to a frozen surface-water body was assumed to represent groundwater that has migrated offsite to downgradient water bodies. Summary statistics and the surface-water EPC are presented in Table 3-10.

3.1.3.3 Exposure Parameters

Exposure parameter values that were identified for each receptor at the site for the PPRTV scenario are provided in Table 3-12. The exposure parameters were based primarily on those provided in ADEC (2010a) and USEPA (1989, 1991, 1997a and 2004a) as well as other sources, as noted. These exposure parameters meet or exceed the USEPA (1989) approach for estimating reasonable maximum exposure (RME), which is the maximum exposure that is reasonably expected to occur in a population. Its intent is to estimate a health-protective exposure case (i.e., well above the average case) that is still within the range of possible exposures (USEPA 1989). Mathematically, the RME estimate for each exposure pathway combines upper percentile values and assumptions with selected average values and assumptions. The upper percentile assumptions tend to maximize estimates of exposure, such as choosing a value near the high end of the concentration or intake range. Therefore, the RME estimates tend to be at the high end of the exposure range, generally greater than the 90^{th} percentile of the population.

3.1.3.4 Assessment of Potential Lead Exposures

The potential hazard associated with lead exposure was evaluated by comparing the predicted blood-lead concentrations to the Centers for Disease Control and Prevention (CDC) blood-lead threshold concentration. The threshold lead concentration is 10 micrograms per deciliter (µg/dL) of whole blood based on potentially adverse neurological effects in children (CDC 2011). A blood-lead concentration of less than 10 µg/dL was deemed acceptable. The USEPA's (2009b) Adult Lead Model (ALM) model, which estimates the blood-lead levels of workers and the fetus of a pregnant worker, was used to evaluate the potential onsite exposure to lead in groundwater for the receptors evaluated.

3.2 Toxicity Assessment

The toxicity assessment identified toxicity values that relate exposure (dose) to potential risk or hazard for each COPC. Toxicity values derived from dose-response data were combined with estimates of exposure to characterize potential noncarcinogenic hazard and carcinogenic risk (see Section 3.3.2). Toxicity profiles were provided for risk/hazard drivers and sulfolane. Selection of toxicity values followed the hierarchies described below.

3.2.1 Noncarcinogenic Toxicity Values

Chronic and subchronic reference doses (RfDs) were used to evaluate potential adverse effects from ingestion, dermal and inhalation (dust) exposures to noncarcinogenic COPCs. Chronic RfDs, which correspond to 7 or more years of exposure, are specifically developed to be protective of long-term exposures to a constituent with a considerable health-protective margin of safety, which is usually over 1000-fold. The USEPA (1989) defines the chronic RfD as "a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime."

The following sources were used to identify chronic toxicological reference values:

- USEPA (2012a) IRIS.
- USEPA PPRTVs, derived by the USEPA's Superfund Health Risk Technical Support Center for the USEPA Superfund program. Current values were obtained directly from the USEPA.
- California Environmental Protection Agency (CalEPA) reference exposure levels from the California Office of Health Hazard Environmental Assessment (OEHHA).
- ATSDR Minimal Risk Levels (MRLs) (ATSDR 2012) Chronic MRLs were used to evaluate chronic exposure.
- USEPA (1997b) Health Effects Assessment Summary Tables (HEAST).

The USEPA (1989) defines exposures lasting between 2 weeks and 7 years as subchronic exposures. As a result, the short-duration and intermittent nature of construction/trench worker and infant exposures required consideration of subchronic toxicity values (subchronic RfDs) to estimate the potential for effects. Subchronic RfDs are developed to be protective of subchronic exposures to constituents with a conservative measure of safety (USEPA 1989). Subchronic RfDs for ingestion (oral) and inhalation (dust and vapor) exposure were identified from the following sources, in the following order of priority:

- USEPA PPRTVs. Current values were obtained directly from the USEPA.
- ATSDR MRLs (ATSDR 2012). Intermediate MRLs were used to evaluate subchronic exposure.
- USEPA (1997b) HEAST.

For the PPRTV Scenario, in addition to chronic RfDs, subchronic RfDs, if available, were used to evaluate potential exposures to onsite construction/trench workers and offsite infants. If subchronic RfDs were unavailable, then only chronic RfDs were used. For the PPRTV Scenario, chronic RfDs were used for offsite children.

Current USEPA guidance recommends calculating a dermal RfD by multiplying the oral RfD by the percent oral absorption efficiency (ABSGI). This recommendation requires one of the following:

- A critical study upon which the toxicity value is based employed an administered dose (e.g., delivery in diet or by gavage) in its design.

- A scientifically defensible database exists that demonstrates that the gastrointestinal absorption of the constituent in question from a medium (e.g., water, feed) similar to the one employed in the critical study is significantly less than 100 percent (e.g., less than 50 percent).

Values for ABSGI were obtained from RAGS (USEPA 2004a). Chronic and subchronic RfDs are presented in Table 3-13.

3.2.2 Carcinogenic Toxicity Values

Oral cancer slope factors (CSFs) and inhalation unit risk (IUR) factors were used to evaluate potential carcinogenic effects from ingestion, dermal and inhalation exposures to COPCs. CSFs quantitatively describe the relationship between dose and response. A CSF represents the 95% UCL of the slope of the dose-response curve and is derived using a low-dose extrapolation procedure that assumes linearity at low doses. By applying a CSF to a particular exposure level of a potential carcinogen, the upper bound lifetime probability of an individual developing cancer related to that exposure can be estimated.

CSFs have been developed for the oral and inhalation (dust particulates) exposure routes; IURs have been developed for the inhalation exposure route. CSFs for oral and IURs for inhalation exposures were identified from the following sources, in the following descending order of priority:

- USEPA (2012a) IRIS.
- USEPA PPRTVs. Current values were obtained directly from the USEPA.
- CalEPA (2012) OEHHA Toxicity Criteria Database.
- USEPA (1997b) HEAST.

As is the case for noncarcinogenic toxicity, the USEPA has not developed dermal CSFs for use in risk assessment. Dermal CSFs were calculated in a manner similar to that of noncarcinogenic RfDs for dermal exposure by dividing the oral CSFs by the ABSGI AF (USEPA 2004a). CSFs are presented in Table 3-13.

3.2.3 Sulfolane Toxicity Values

Toxicity values for sulfolane are not presented in IRIS (USEPA 2012a). However, a PPRTV chronic oral RfD of 0.001 mg/kg-day and a PPRTV subchronic oral RfD of 0.01 mg/kg-day have been prepared for sulfolane (USEPA 2012b).

The PPRTV Scenario risk assessment presents estimated hazards for potential sulfolane exposures using the USEPA (2012b) PPRTV oral RfDs for sulfolane

3.2.4 Toxicity Equivalence Factors for Polynuclear Aromatic Hydrocarbons

As shown in Tables 3-2a and 3-2b, some carcinogenic PAHs have been identified as COPCs in soil. Following ADEC (2010a) guidance, toxicity equivalence factors (TEFs) were used to assess risks to carcinogenic PAHs, including benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene and indeno(1,2,3-c,d)pyrene). TEFs were applied to EPCs of all carcinogenic PAHs in surface and subsurface soil to equivalent concentrations of benzo(a)pyrene (USEPA 2011c) and total risk was derived for the carcinogenic PAH COPCs. The assessment of potential exposures to other PAHs also included PAHs identified as COPCs in soil based on analytical data collected during the 2011 field season.

3.3 Risk Characterization – Provisional Peer Reviewed Toxicity Value Scenario

This section presents the PPRTV Scenario and provides estimated ELCRs and hazard indices (HIs) for potentially complete and significant exposure pathways identified in Section 3.1.1.4 for on- or offsite potential receptors, based on the USEPA (2012a) PPRTV toxicity criteria for sulfolane and the exposure parameters presented in Table 3-12.

3.3.1 Risk Characterization – PPRTV Scenario

The risk characterization integrates results of the data evaluation, exposure assessment and toxicity assessment to evaluate potential risks associated with exposure to site COPCs. The basis for the risk characterization is the quantitative evaluation of potential exposure by potential receptors to COPCs, which consists of estimating carcinogenic risk and noncarcinogenic hazard. This quantitative evaluation of risk and hazard generally provides a health-protective representation of the upper end (potentially highest exposures) for a receptor. The quantitative methods used to calculate noncarcinogenic hazard and carcinogenic risk are presented below. Consistent with USEPA (1989) guidance, the potential for carcinogenic and noncarcinogenic risks were evaluated separately.

3.3.1.1 Carcinogenic Risk

For potential carcinogens, risk was estimated as the incremental probability of an individual developing cancer during a lifetime as a result of RME to a potential carcinogen and was calculated as follows:

$$ELCR = LADDi \times CSFi$$

Where:

ELCR = excess lifetime cancer risk (unitless)

LADDi = lifetime average daily dose for the *i* th constituent (mg/kg BW-day)

CSFi = cancer slope factor for the *i* th constituent $(\text{mg/kg BW-day})^{-1}$.

The CSF converts intake averaged over a lifetime of exposure to the incremental lifetime risk of an individual developing cancer. This linear equation is only valid at low risk levels (i.e., below estimated risks of one in 100) and is an upper-bound estimate based on the 95% UCL of the slope of the dose-response curve. Therefore, the actual risk will be lower than the predicted risk. Potential risk was assumed to be additive, and risks from different possible and probable carcinogens and pathways were summed to evaluate the overall risk. Pathway-specific risks were calculated as the sum of risks from potential carcinogenic COPCs within each exposure pathway, and the total ELCR for each receptor was calculated by summing the risk estimates for the exposure pathways evaluated.

For inhalation of COPCs, the following equation from USEPA (2009a) RAGS Part F was used to assess ELCRs:

$$ELCR = LAEC * IUR$$

Where:

ELCR = excess lifetime cancer risk (unitless)

LAEC = lifetime average exposure concentration $(\mu g/m^3)$

IUR = inhalation unit risk $(\mu g/m^3)^{-1}$

Scientific notation was used to express potential carcinogenic risks. For example, a value of 1×10^{-6} is equal to one in 1 million (or 0.000001). For individual constituents, the ADEC (2010a) compares risk estimates to an acceptable cumulative ELCR of 1×10^{-5}. The acceptable cancer risk (or range of risks) is the incremental risk attributed to the estimated upper-bound exposure (i.e., RME) to COPCs at the site. This acceptable risk is, by definition, independent of risks associated with non-site-related constituent exposures and other background cancer risks (USEPA 1989).) It is standard USEPA and ADEC practice, however, to assess risks and hazards first with background constituents included and then discuss the risks in the absence of the background impacts to inform the decision makers about the risks of site-related constituents.

3.3.1.2 Noncarcinogenic Hazard

The HQ approach was used to characterize the overall potential for noncarcinogenic effects associated with exposure to multiple constituents. This approach assumes that chronic and subchronic exposures to multiple constituents are additive. For direct contact and inhalation of particulates exposures, the HQ was calculated as follows:

$$HQ = ADD / RfD$$

Where:

HQ = hazard quotient (unitless)

ADD = average daily dose (mg/kg-day)

RfD = reference dose $(\text{mg/kg-day})^{-1}$

For inhalation of volatile COPCs, the following equation from USEPA (2009a) RAGS Part F was used to assess noncancer hazards:

$$HQ = AEC / RfC$$

Where:

HQ = hazard quotient (unitless)

AEC = average exposure concentration (micrograms per cubic centimeter [$\mu g/cm^3$])

RfC = inhalation reference concentration $(\mu g/cm^3)^{-1}$

The HQ represents the comparison of exposure (dose) over a specified period of time to an RfD for a similar time period. The estimates of exposure (dose) were calculated based on chronic or subchronic exposures. If the HQ exceeds a value of 1, there is a possibility of adverse health effects. The magnitude of the HQ is not a mathematical prediction of the severity or incidence of the effects, but rather indicates that effects may occur. The likelihood of effects occurring at levels above an HQ=1 is based on the nature of the effects used to set the RfD and the magnitude of the composite uncertainty factor used in the RfD derivation. The constituent HQs were summed to calculate an HI for a pathway or site, and the USEPA (1989) recommends that the total HI for the constituents and pathways assessed not exceed a value of 1. An HI of less than 1 indicates that adverse health effects are not likely to occur from exposure to assessed constituents. HQs or HIs of greater than 1 do not indicate that significant risks are present, but rather that additional evaluation may be required to better define the level of risk.

According to the USEPA (1989), noncarcinogenic effects should be evaluated based on target organ(s) or toxicity endpoints. The USEPA believes that the assumption of dose additivity is one of the major limitations of the HI approach because it may overestimate the potential for health effects that most likely will not occur if the COPCs affect different organs or act by different mechanisms of action. The USEPA counters the potential for overestimation by specifying segregation of COPCs by effect and mechanism of action, and derivation of separate HIs for each group (USEPA 1989). If the total HI exceeds a value of 1, the specific substances will be evaluated so that only substances that affect similar target organs or exhibit a similar mode of action (i.e., similar effects in the same target organs via the same mechanism) are summed. Quantitative estimates of carcinogenic risk and noncarcinogenic hazard were presented for each receptor.

3.3.1.3 Risk Characterization of Petroleum Hydrocarbon Compounds

In accordance with ADEC (2008b) Cumulative Risk Guidance, individual risks from exposure to GRO, DRO and RRO were calculated using RfDs provided by ADEC (2010a). However, these risk calculations were not included in cumulative risk estimates. Consistent with ADEC (2008b) Cumulative Risk Guidance, cumulative risks for each receptor were estimated using indicator constituents, as discussed below.

In general, quantitative risk calculated from individual petroleum constituents is considered adequate to account for risk in cumulative risk calculations from petroleum mixtures (ADEC 2008b). The key constituents of petroleum products associated with risk (e.g., PAHs, BTEX, methyl tertiary butyl ether) are included in the quantitative cumulative risk calculations and should adequately describe human health risk from exposure to site media.

3.3.2 Estimated Risks and Hazards for Provisional Peer Reviewed Toxicity Value Scenario

For each total estimated ELCR and HI, the primary exposure pathway and contributing COPC(s) are indicated, as appropriate. This section presents ELCRs and hazards for potential onsite receptors (Section 3.3.2.1) and potential offsite receptors (Section 3.3.2.2). For each potential receptor, ELCRs and/or HIs are summarized based on possible exposure to maximum and/or 95% UCL-based EPC COPC concentrations. Appendices D and E present complete risk calculations for ELCRs and HIs based on maximum and 95% UCL COPC concentrations, respectively.

Summaries of the cumulative ELCRs and estimated HIs for the receptors evaluated under the PPRTV Scenario are presented in the following tables:

- Tables 3-14 and 3-15 present the ELCR and HI summaries for on and offsite receptors using the maximum detected on and offsite values and the 95% UCL on and offsite values, respectively.
- Tables 3-14, 3-16a and 3-17a present ELCR and HI summaries for potential on and offsite receptors based on maximum COPC concentrations for all wells in each EU (including EU-1 because the maximum for all offsite wells is located in this EU).
- Table 3-15 presents ELCR and HI summaries for potential on and offsite receptors at EU-1 based on 95% UCL EPCs.
- Table 3-16a presents ELCR and HI summaries for offsite receptors based on maximum COPC concentrations at EU-2 wells.
- Table 3-17a presents ELCR and HI summaries for offsite receptors based on maximum COPC concentrations at EU-3 wells.

The PPRTV scenario risk assessments are presented in Appendix D (maximum concentrations) and Appendix E (95% UCL EPCs). Appendix H provides toxicity profiles for the primary risk and hazard drivers, including: arsenic, benzene, naphthalene, sulfolane, 1,3,5-trimethylbenzene and xylenes.

The total estimated ELCRs presented in Tables 3-14 through 3-17b include arsenic as a soil COPC (arsenic was excluded as a COPC in groundwater). Based on an evaluation of arsenic in soil samples at the site, the presence of arsenic is due to background concentrations. Detected concentrations of arsenic in soil samples collected at the site are evaluated in the 2012 Revised Site Characterization Report (Barr 2012). This evaluation compared site arsenic concentrations to background studies collected in Alaska and evaluated the spatial distribution of arsenic with respect to site operations and other COPCs. The results of the evaluation concluded that the presence of arsenic in soil does not appear to be associated with refinery operations and is likely a result of background concentrations.

3.3.2.1 Estimated Risks and Hazards for Potential Onsite Receptors

Potential onsite receptors evaluated include current and future indoor and outdoor commercial workers, construction/trench workers and adult visitors. The USEPA (2012b) chronic PPRTV oral RfD was used to evaluate potential sulfolane exposures. The maximum onsite concentration of sulfolane in groundwater detected above the laboratory reporting limit between 2009 and 2011 is 10.4 mg/L. Estimated risks and hazards for the onsite receptors using maximum detected concentrations and 95% UCLs as EPCs are summarized in Table 3-14 and Table 3-15, respectively.

3.3.2.1.1 Onsite Indoor Commercial/Industrial Workers

Table D-1 (Appendix D) presents the estimated ELCRs and HIs for indoor commercial/industrial workers, based on exposures to maximum detected COPC concentrations in groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors (see Table 3-14). The total estimated ELCR is 1×10^{-5} and the total estimated HI is 0.2.

Table E-1 (Appendix E) presents the estimated ELCRs and HIs for indoor commercial/industrial workers, based on exposures to 95% UCLs of detected COPC concentrations in groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors (see Table 3-15). The total estimated ELCR is 1×10^{-6} and the total estimated HI is 0.02.

3.3.2.1.2 Onsite Outdoor Commercial/Industrial Workers

Table D-2 (Appendix D) presents the estimated ELCRs and HIs for outdoor commercial/industrial workers, assuming potential exposure to 95% UCLs of COPC concentrations in surface soil. Table D-2 also shows estimated ELCRs and HIs based on direct-contact exposures, including ingestion of, dermal contact with and inhalation of dust particles from surface soil. The total estimated ELCR is 5×10^{-6} and the total estimated HI is 0.05 (see Table 3-14). Soil ingestion contributes most to the total estimated ELCR and HIs. Arsenic is the primary risk and hazard driver. Excluding the estimated arsenic ELCR and HI, which are likely due to background, the total estimated ELCR is 2×10^{-7} and the total estimated HI is 0.03 (see Table D-2).

3.3.2.1.3 Onsite Construction/Trench Workers

The USEPA (2012b) PPRTV subchronic oral RfD for sulfolane was used to estimate potential construction/ trench worker hazards. Table 3-14 and Table D-3a (Appendix D) present the estimated ELCRs and HIs for construction/trench workers based on potential exposures to maximum COPC concentrations in surface and subsurface soil, assuming direct-contact exposures including ingestion, dermal contact and inhalation of dust particles. The total estimated ELCR associated with potential exposure to COPCs in soil is 1 x 10^{-6} and the total estimated HI is 0.3. The soil ingestion pathway contributes most to the total soil-related estimated ELCR and HI. Excluding the estimated arsenic ELCR, which is likely based on background, the total estimated ELCR is 3 x 10^{-7} and the total estimated HI is 0.3.

Table 3-14 and Table D-3b (Appendix D) present ELCRs and HIs based on incidental ingestion of and dermal contact with groundwater in an onsite excavation trench, and inhalation of VOCs within trench air from groundwater based on maximum COPC concentrations in groundwater. The total estimated ELCR is 3 x 10^{-4} and the total estimated HI is 49. Inhalation of VOCs in the trench air is the exposure pathway that contributes most to the cumulative ELCR and HIs. Benzene, naphthalene and ethylbenzene (as estimated in trench air from groundwater) are the primary risk drivers for the total ELCR. Benzene, naphthalene, xylenes and 1,3,5-trimethylbenzene are the risk drivers for the HI.

Table 3-15 and Table E-3a (Appendix E) present the estimated ELCRs and HIs for construction/trench workers based on 95% UCL COPC concentrations and direct-contact exposures including ingestion of, dermal contact with and inhalation of dust particles in surface and subsurface soil. The total soil-related estimated ELCR is 3 x 10^{-7} and the total soil-related estimated HI is 0.06. Soil ingestion contributes most to the total estimated ELCR and HIs. Excluding the estimated arsenic ELCR and HI, which are likely based on background, the total estimated ELCR is 2 x 10^{-8} and the total estimated HI is 0.05.

Table 3-15 and Table E-3b (Appendix E) present ELCRs and HIs based on incidental ingestion of and dermal contact with groundwater in an onsite excavation trench and inhalation of VOCs within trench air from groundwater based on 95% UCL COPC concentrations. The total estimated ELCR is 3 x 10^{-5} and the total estimated HI is 9. Inhalation of VOCs in the trench air contributes most to ELCR and HIs. Benzene is the primary risk driver for ELCRs and benzene and naphthalene are the primary risk drivers for HIs.

3.3.2.1.4 Onsite Adult Visitors

Table 3-14 and Table D-4 (Appendix D) present the estimated ELCRs and HIs for adult visitors based on maximum COPC concentrations in onsite groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors. The total estimated ELCR is 2 x 10^{-7} and the total estimated HI is 0.002.

Table 3-15 and Table E-4 (Appendix E) present the estimated ELCRs and HIs for adult visitors based on 95% UCL COPC concentrations in onsite groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors. The total estimated ELCR is 1 x 10^{-8} and the total estimated HI is 0.0004.

3.3.2.2 Estimated Risks and Hazards for Potential Offsite Receptors

Potential offsite receptors evaluated include current and future residents; adults (chronic exposures), children (chronic exposures) and infants (subchronic exposures); indoor and outdoor commercial workers (chronic exposures); and construction/trench workers (subchronic exposures). The estimated risks and hazards for offsite receptors using maximum detected concentrations and 95% UCLs as EPCs are summarized in Table 3-14 and Table 3-15 , respectively.

3.3.2.2.1 Offsite Adult, Child and Infant Residents

Table 3-14 and Tables D-5a and D-6a (Appendix D) present the estimated ELCRs and HIs for offsite adult and child residents, assuming potential exposure to 95% UCL COPC concentrations in ambient air from onsite surface soil (based on 95% UCL concentrations) using the USEPA (2012b) chronic PPRTV oral RfD for sulfolane. The total estimated ELCRs for adult and child residents are 4×10^{-8} and 9×10^{-9}, respectively, and the total estimated HIs are both 0.001. Excluding arsenic in soil and the estimated arsenic ELCRs and HIs, which is likely due to background, the total estimated ELCRs for adult and child residents are 4×10^{-8} and 8×10^{-9}, respectively, and the total estimated HIs are both 0.0009 (see Table D-5a [Appendix D] for adult resident and Table D-6a for child resident). Table D-7a presents the estimated ELCR and HI for offsite infant residents, assuming potential exposure to 95% UCL COPC concentrations in ambient air from onsite surface soil using the USEPA (2012b) subchronic PPRTV oral RfD for sulfolane. The total estimated ELCR for infant residents is 1×10^{-9} and the total estimated HI is 0.0007. Excluding the estimated arsenic ELCR and HI, which is likely due to background, the total estimated ELCR for infant residents is 1×10^{-9} and the total estimated HI is 0.0005.

Table 3-14 and Tables D-5b, D-6b and D-7b (Appendix D) show HIs based on ingestion of the maximum detected concentration of sulfolane in groundwater (i.e., tapwater), applied across the entire offsite area (which also includes EU-1 because the maximum value occurs in this EU), for adults (chronic exposures; Table D-5b), children (chronic exposures; Table D-6b) and infants (subchronic exposures; Table D-7b), respectively. Tables D-5c, D-6c and D-7c present the HIs associated with ingestion of homegrown produce irrigated with sulfolane-impacted groundwater (maximum detected concentration) for adults (chronic exposures; Table D-5c), children (chronic exposures; Table D-6c) and infants (subchronic exposures; Table D-7c), respectively. Tables D-11 and D-12 present the HIs associated with ingestion of surface water (maximum detected concentration) for adults (chronic exposures; Table D-11) and children (chronic exposures; Table D-12).

As shown in Table 3-14 and Tables D-5b, D-6b and D-7b (Appendix D), using the PPRTV oral RfDs for sulfolane and the maximum concentration detected in offsite groundwater, the total estimated HIs associated with ingestion of groundwater are 12 for adult residents (chronic exposure; Table D-5b), 28 for child residents (chronic exposure; Table D-6b) and 7 for infant residents (subchronic exposure; Table D-7b), respectively, based on ingestion of tapwater. Table 3-14 and Tables D-5c, D-6c and D-7c present the total estimated HIs associated with ingestion of homegrown produce, including an HI of 0.8 for adult residents (chronic exposure; Table D-5c), 2 for child residents (chronic exposure; Table D-6c) and 0.3 for infant residents (subchronic exposure; Table D-7c), respectively. These HIs are based on ingestion of homegrown produce using the USEPA (2012b) PPRTV oral RfDs for sulfolane, along with the maximum detected offsite sulfolane concentration, a BCF of 1.0 and the 95th percentile *per capita* produce ingestion rates. These exposure assumptions were used in all of the produce ingestion scenarios presented in this paragraph. As shown in Table 3-14 and Tables D-11 and D-12 (Appendix D), using the PPRTV oral RfDs for sulfolane and the maximum concentration EPC, the total estimated HIs associated with ingestion of surface-water are 0.03 for adult residents (chronic exposure; Table D-11) and 0.2 for child residents (chronic exposure; Table D-12). The surface-water HIs for this receptor group are the same for each EU (Table 3-15, Table 3-16a and Table 3-17a).

Table 3-14 presents the cumulative HIs for this receptor group for all exposure pathways combined based on maximum EPCs which are 13 for adult residents, 31 for child residents (chronic exposure), and 7 for infant residents (subchronic exposure). Table 3-14 also presents the cumulative ELCRs for this receptor group for all exposure pathways combined based on maximum EPCs which are 4×10^{-8} for adult residents, 9×10^{-9} for child residents (chronic exposure), and 1×10^{-9} for infant residents (subchronic exposure).

Table 3-15 and Tables E-5a, E-6a and E-7a (Appendix E) present the estimated ELCRs and HIs for adults, children (chronic) and infant (subchronic) residents, respectively, based on inhalation of fugitive windborne dust or vapors from onsite COPCs in surface soil, assuming 95% UCL COPC concentrations. As shown in Table E-5a the total estimated ELCR is 4×10^{-8} and the total estimated HI is 0.001 for adult residents (chronic exposure; Table E-5a). For a child resident (chronic exposure), the total estimated ELCR is 9×10^{-9} and the total estimated HI is 0.001 (Table E-6a). The total estimated ELCR is 1×10^{-9} and the total estimated HI is 0.0007 for the infant resident (subchronic exposure; Table E-7a).

Assuming the 95% UCL concentration for sulfolane in EU-1, Table 3-15 and Tables E-5b, E-6b and E-7b in Appendix E) show estimated HIs based on ingestion of 95% UCL sulfolane concentrations in groundwater (i.e., tapwater) at EU-1 by resident receptors. Using the USEPA (2012b) PPRTV oral RfDs for sulfolane, the estimated HIs associated with ingestion of water are 5 for the adult resident (chronic exposure; Table E-5b), 11 for child resident (chronic exposure; Table E-6b) and 3 for infant resident (subchronic exposure; Table E-7b). Tables E-5c, E-6c and E-7c present the total estimated HIs associated with consumption of homegrown produce irrigated with water containing sulfolane in EU-1. The HIs are 0.3 for adult residents (chronic exposure), 0.9 for child residents (chronic exposure) and 0.1 for an infant resident (subchronic exposure), using the USEPA (2012b) PPRTV oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 3-16a and Tables D-13a, D-13b, D-14a, D-14b, D-15a and D-15b (Appendix D) present HIs based on ingestion of the maximum sulfolane concentration in groundwater (i.e., tapwater) within EU-2 for resident receptors. Using the USEPA (2012b) PPRTV oral RfDs for sulfolane, the total estimated HIs associated with ingesting tapwater containing maximum sulfolane concentrations in EU-2 are 4 for an adult resident (chronic exposure; Table D-13a), 9 for a child resident (chronic exposure; Table D-14a) and 2 for an infant resident (subchronic exposure; Table D-15a). In addition, Table 3-16a presents HIs associated with consumption of homegrown produce irrigated with groundwater containing the maximum sulfolane concentrations at EU-2. The estimated HIs for consumption of homegrown produce irrigated with water from EU-2 are 0.3 for an adult resident (chronic exposure; Table D-13b), 0.8 for a child resident (chronic exposure; Table D-14b) and 0.1 for an infant resident (subchronic exposure; Table D-15b), using the USEPA (2012b) PPRTV oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 3-16b and Tables E-11a, E-12a and E-13a (Appendix E) present HIs based on ingestion of the 95% UCL sulfolane concentration in groundwater (i.e., tapwater) within EU-2 for resident receptors. Using the USEPA (2012b) PPRTV oral RfDs for sulfolane, the total estimated HIs associated with ingesting tapwater containing sulfolane in EU-2 are 2 for an adult resident (chronic exposure; Table E-11a), 4 for a child resident (chronic exposure; Table E-12a) and 0.9 for an infant resident (subchronic exposure; Table E-13a). In addition, Table 3-16b and Tables E-11b, E-12b and E-13b (Appendix E) present HIs associated with consumption of homegrown produce irrigated with sulfolane-impacted groundwater at EU-2. The total estimated HIs for consumption of homegrown produce irrigated with water from EU-2 are 0.1 for an adult resident (chronic exposure; Table E-11b), 0.3 for a child resident (chronic exposure; Table E-12b) and 0.04 for an infant resident (subchronic exposure; Table E-13b) respectively, using the USEPA (2012b) PPRTV oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 3-17a and Tables D-19a, D-20a and D-21a (Appendix D) show the estimated HIs based on ingestion of the maximum sulfolane concentration in groundwater (i.e., tapwater) within EU-3 by resident receptors. Using the USEPA (2012b) PPRTV oral RfDs for sulfolane, the estimated HIs associated with ingestion of tapwater are 2 for an adult resident (chronic exposure; Table D-19a), 5 for a child resident (chronic exposure; Table D-20a) and 1 for an infant resident (subchronic exposure; Table D-21a). In addition to a drinking water scenario, Table 3-17a and Tables D-19b, D-20b and D-21b (Appendix D) present the HIs associated with consumption of homegrown produce irrigated with the maximum detected sulfolane concentration in groundwater in EU-3. The estimated HIs for consumption of homegrown produce are 0.1 for an adult resident (chronic exposure; Table D-19b), 0.4 for a child resident (chronic exposure; Table D-20b) and 0.06 for an infant resident (subchronic exposure; Table D-21b), using the USEPA (2012b) PPRTV oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 3-17b and Tables E-17a, E-18a and E-19a (Appendix E) show the estimated HIs based on ingestion of the 95% UCL sulfolane concentration in groundwater (i.e., tapwater) within EU-3 by resident receptors. Using the USEPA (2012b) PPRTV oral RfDs for sulfolane, the estimated HIs associated with ingestion of tapwater are 0.3 for an adult resident (chronic exposure; Table E-17a), 0.7 for a child resident (chronic exposure; Table E-18a) and 0.2 for an infant resident (subchronic exposure; Table E-19a). In addition to a drinking water scenario, Table 3-17b and Tables E-17b, E-18b and E-19b (Appendix E) present the HIs associated with ingestion consumption of homegrown produce irrigated with sulfolane-impacted groundwater in EU-3. The estimated HIs for consumption of homegrown produce are 0.02 for an adult resident (Table E-17b), 0.05 for a child resident (chronic exposure; Table E-18b) and 0.007 for an infant resident (subchronic exposure; Table E-19b), using the USEPA (2012b) PPRTV oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

3.3.2.2.2 Offsite Indoor Commercial Workers

Table 3-14 and Table D-8 (Appendix D) show the HI based on ingestion of groundwater (i.e., tapwater), assuming the maximum offsite sulfolane concentration and the USEPA (2012b) PPRTV oral RfD for sulfolane. The total estimated HI is 9 for offsite indoor commercial/industrial workers (chronic exposure) based solely on ingestion of tapwater containing sulfolane (see Table D-8 [Appendix D]).

Table 3-15 and Table E-8 (Appendix E) show the HI based on ingestion of groundwater (i.e., tapwater), assuming the 95% UCL offsite sulfolane concentration for EU-1 and the USEPA (2012b) PPRTV oral RfD for sulfolane. The total estimated HI is 3 for offsite indoor commercial/industrial workers (chronic exposure) based solely on ingestion of tapwater containing sulfolane (see Table E-8 [Appendix E]).

At EU-2, two sulfolane groundwater EPCs were used to estimate potential hazards associated with ingestion of groundwater by offsite indoor commercial/industrial workers (chronic exposure). Using the maximum detected offsite sulfolane concentration at EU-2, the estimated HI is 3 (Table 3-16a). Comparatively, the HI based on the 95% UCL sulfolane concentration at EU-2 is 1. Both HIs were derived using the USEPA (2012b) PPRTV oral RfD for sulfolane (see Table D-16 [Appendix D] for maximum EPC and Table E-14 [Appendix E] for 95%UCL). Similarly, two sulfolane groundwater EPCs were used to estimate potential hazards associated with ingestion by offsite indoor commercial/industrial workers (chronic exposure) at EU-3. Table 3-17a shows the HI based on ingestion of groundwater (i.e., tapwater), assuming the maximum offsite sulfolane concentration at EU-3 and Table 3-17b shows the corresponding HI based the 95% UCL offsite sulfolane concentration at EU-3. Both HIs were derived using the USEPA (2012b) PPRTV oral RfD for sulfolane. Using the maximum detected sulfolane concentration at EU-3, the estimated HI is 2; the estimated HI is 0.2 for offsite indoor commercial/industrial workers (chronic exposure) based on the 95% UCL groundwater concentration at EU-3 (see Table D-22 [Appendix D] and Table E-20 [Appendix E], respectively).

3.3.2.2.3 Offsite Outdoor Commercial Workers

Table 3-14 presents the estimated ELCRs and HIs for offsite outdoor commercial workers potentially exposed via inhalation of dust particles from onsite surface soil (0 to 2 feet bgs), using 95% UCL COPC concentrations in onsite surface soil. The total estimated ELCR is 2 x 10^{-8} and the total estimated HI is 0.0006 (see Table D-9a [Appendix D]). Excluding the estimated arsenic concentrations in surface soil and HI, which are likely attributable to background, the total estimated ELCR is 2 x 10^{-8} and the total estimated HI is 0.0006 (Table D-9a). Table 3-14 also shows the HI for this receptor assuming ingestion of groundwater (i.e., tapwater) and assuming the maximum offsite sulfolane concentration. The estimated HI is 9 for offsite outdoor commercial/industrial workers, based on ingestion of tapwater (see Table D-9b [Appendix D]).

Table E-9a [Appendix E] shows ELCRs and HIs based on inhalation of fugitive windborne dust and vapors from onsite COPCs in surface soil, based on 95% UCL COPC concentrations and the USEPA (2012b) PPRTV oral RfD for sulfolane. It was assumed that the offsite outdoor commercial worker (chronic exposure) is located at the site boundary; therefore, the estimated ELCRs and HIs calculated for onsite commercial workers represent a health-protective estimate for an offsite commercial worker, based on inhalation of dust and vapors from the site. As shown in Table E-9a [Appendix E], the total estimated ELCR is 2 x 10^{-8} and the total estimated HI is 0.0006, based on inhalation of dust and vapors in ambient air (see Table E-9a [Appendix E]).

Assuming the 95% UCL and USEPA (2012b) PPRTV oral RfD for sulfolane in EU-1, the total estimated HI is 3 for offsite outdoor commercial/industrial workers (chronic exposure), based on ingestion of groundwater (see Table 3-15 and Table E-9b [Appendix E]).

At EU-2, two sulfolane groundwater EPCs were used to estimate potential hazards associated with ingestion of groundwater: the maximum detected concentration of sulfolane and the 95% UCL of the mean sulfolane concentrations. Using the maximum detected concentration in groundwater at EU-2, the estimated HI is 3 for offsite outdoor commercial/industrial workers (chronic exposure) based on ingestion of groundwater (see Table 3-16a and Table D-17 [Appendix D]). Using the 95% UCL sulfolane concentration, the total estimated HI is 1 for offsite outdoor commercial/industrial workers at EU-2, based on ingestion of tapwater (chronic exposure; see Table 3-16b and Table E-15 [Appendix E]). Both hazard estimates used the USEPA (2012b) PPRTV oral RfD for sulfolane.

Similarly, at EU-3, the 95% UCL and maximum sulfolane groundwater concentrations were both evaluated as distinct EPCs to estimate potential hazards associated with ingestion of groundwater by offsite commercial/industrial workers. Using the maximum sulfolane concentration at EU-3, the estimated HI is 2 (Table 3-17a and Table D-23 [Appendix D]). Using the 95% UCL sulfolane concentration, the estimated HI is 0.2 for offsite outdoor commercial/industrial workers at EU-3 (see Table 3-17b and Table E-21 [Appendix E]). Both hazard estimates are used the USEPA (2012b) PPRTV oral RfD for sulfolane.

3.3.2.2.4 Offsite Construction/Trench Workers

The estimated HIs for an offsite construction worker who is potentially exposed to maximum sulfolane concentrations by incidental ingestion of sulfolane in offsite groundwater in excavation trenches is 0.0008 (see Table 3-14 and Table D-10 [Appendix D]). This exposure is subchronic and the HI is derived assuming the maximum offsite sulfolane concentration and using the USEPA (2012b) PPRTV subchronic oral RfD for sulfolane. As discussed in Section 3.1.1.4, sulfolane is not considered to pose adverse health effects due to inhalation and dermal contact exposures. The total estimated HI is 0.0008 for offsite construction workers, based on incidental ingestion of groundwater while working in trenches.

Tables 3-15, 3-16b and 3-17b show the HIs for potential exposures by the construction worker (subchronic exposure) based on 95% UCL sulfolane concentrations for incidental ingestion of sulfolane in offsite groundwater in excavation trenches in EU-1, EU-2 and EU-3, respectively. The estimated HIs for offsite construction workers, which are based on the USEPA (2012b) PPRTV subchronic oral RfD for potential groundwater ingestion exposures of groundwater while working in trenches, and 95%UCL sulfolane concentrations, are 0.0003, 0.0001 and 0.00002 in EU-1, EU-2 and EU-3, respectively (see Tables E-10, E-16 and E-22 [Appendix E] for the hazard calculations for this receptor in EU-1, EU-2 and EU-3, respectively). Tables 3-16a and 3-17a show the corresponding HIs for this receptor group based on the maximum sulfolane groundwater concentrations at EU-2 and EU-3, respectively. The estimated HIs for offsite construction workers exposed to maximum groundwater concentrations at EU-2 and EU-3 are 0.0003 and 0.0001, respectively (see Tables D-18 and D-24 [Appendix D]).

3.3.2.2.5 Offsite Adult and Child Recreational Users

Table 3-14 and Tables D-11 and D-12 (Appendix D) show the estimated HIs for offsite adult and child (aged 1 to 6years) recreational users (i.e., swimmer who may be exposed by incidental, ingestion of sulfolane in surface water), assuming the maximum offsite sulfolane concentration in pore water and the USEPA (2012b) PPRTV chronic oral RfD for sulfolane. The total estimated HIs are 0.03 and 0.2 for offsite adult (chronic exposure) and child recreational users (chronic exposure), respectively.

3.3.3 Conclusions for Provisional Peer Reviewed Toxicity Value Scenario

Results of this Revised Draft Final HHRA indicate that the estimated ELCRs and HIs, based on maximum onsite COPC concentrations, are at or below the ADEC- established acceptable ELCR of 1×10^{-5} for current and future onsite indoor and outdoor commercial/industrial workers and adult site visitors, and below the target HI of 1 for the PPRTV Scenario. The estimated ELCRs and HIs for current and future onsite construction workers exceed the acceptable ELCR of 1×10^{-5} and target HI of 1 based on maximum COPC concentrations; however, estimated ELCRs are below the acceptable ELCR based on 95% UCL COPC concentrations.

Table 3-14 presents the estimated ELCRs and HIs using maximum COPC concentrations in onsite subsurface soil, maximum onsite COPC surface soil and groundwater concentrations, the single maximum offsite groundwater concentration of sulfolane, and the USEPA (2012b) PPRTV oral RfDs for sulfolane. The estimated HIs are below the target HI of 1 for the onsite commercial/industrial worker, onsite commercial/industrial outdoor worker, onsite visitor and offsite child recreator. The estimated HIs exceed the target HI of 1 for onsite construction/trench workers, offsite residents, and offsite indoor and outdoor commercial workers. The HI is equal to 49 for onsite construction workers based on inhalation of volatile COPCs in trench air from groundwater. Benzene, naphthalene, xylenes and 1,3,5-trimethyl benzene are the hazard drivers. For offsite adult, child and infant resident receptors, the HIs are equal to 13, 31, and 7, respectively.

Similarly, the estimated total ELCRs for the potential onsite visitor (Table 3-14) are below the ADEC acceptable ELCR of 1×10^{-5}. The estimated total ELCRs for the onsite indoor and outdoor commercial workers and onsite construction/trench workers do not exceed the ADEC acceptable ELCR. The total estimated ELCRs are equal to 1×10^{-5} and 5×10^{-6} for onsite indoor and outdoor commercial workers, respectively. The estimated ELCR for the indoor commercial worker is based on inhalation of volatile COPCs in indoor air. For the outdoor commercial worker, the estimated total ELCR is based on soil ingestion including arsenic, which is likely present due to background concentrations. For onsite construction/trench workers, the total estimated ELCR is equal to 3×10^{-4} for onsite construction/trench workers, which is based primarily on inhalation of volatile COPCs in trench air from groundwater, with benzene, naphthalene and ethylbenzene as the primary risk drivers.

Table 3-15 presents the estimated ELCRs and HIs using 95% UCL COPC concentrations in onsite soil and in EU-1, and the USEPA (2012b) PPRTV oral RfDs for sulfolane. Using the 95% UCL onsite COPC soil concentrations, the 95% UCL onsite and EU-1 offsite sulfolane groundwater concentrations, and the USEPA (2012b) PPRTV oral RfDs for sulfolane, the estimated HIs for the receptors evaluated are below the target HI of 1, with the exception of onsite construction/trench workers, offsite residents, and offsite indoor and outdoor commercial workers. The HI is equal to 9 for onsite construction workers based on inhalation of volatile COPCs in trench air from groundwater. Naphthalene and benzene are the hazard drivers. For offsite residents, the estimated total HIs are equal to 5, 12 and 3 for offsite adult, child and infant residents, respectively, with ingestion of sulfolane in tap water the primary hazard driving exposure pathway. For both the offsite indoor commercial worker and the offsite outdoor commercial worker, the estimated HI is 3, based on ingestion of sulfolane in groundwater.

Similarly, the estimated total ELCRs for the potential receptors evaluated at EU-1 are at or below the ADEC acceptable ELCR of 1×10^{-5}, with the exception of onsite commercial/ industrial outdoor workers and onsite construction/trench workers (Table 3-15). For the onsite commercial/ industrial outdoor worker, the total estimated ELCR is equal to 5×10^{-6}. The total estimated ELCR is equal to 3×10^{-5} for onsite construction/trench workers, which is based on inhalation of volatile COPCs in trench air from groundwater with benzene as the risk driver.

Table 3-16a presents the estimated ELCRs and HIs using the maximum COPC sulfolane concentrations in EU-2. Under the PPRTV Scenario using maximum COPC concentrations in EU-2, the HI for offsite construction workers is below the target HI of 1. The estimated HIs exceed the target HI of 1 for offsite adult, child (chronic exposure) and infant residents (subchronic exposure); and offsite indoor and outdoor commercial workers. Ingestion of sulfolane in groundwater is the primary exposure pathway. Using the maximum sulfolane concentration in EU-2, the HI for offsite construction workers is below the target HI of 1.

As shown in Table 3-16b, using the 95% UCL COPC sulfolane concentrations in EU-2, the estimated HIs are either below or equal to the target HI of 1 for offsite infant resident, offsite indoor and outdoor commercial/ industrial worker receptors, and offsite construction workers. The HIs exceed the target HI of 1 for offsite resident adult and child (chronic) receptors, with ingestion of tapwater containing sulfolane as the primary hazard driver.

Table 3-17a presents the estimated ELCRs and HIs using the maximum sulfolane concentrations in EU-3. Under the PPRTV Scenario, HIs exceed the target HI of 1 for offsite adult and child (chronic) residents and for indoor and outdoor commercial/industrial workers. Ingestion of groundwater is the primary exposure pathway. The HI for offsite construction workers is below the target HI of 1.

As shown in Table 3-17b, using the 95% UCL sulfolane concentrations in EU-3, the estimated HIs are below the target HI of 1 for each of the potential offsite receptors.

3.4 Evaluation of Potential Exposures to Lead in Onsite Groundwater

The USEPA's (2009b) ALM was used to evaluate current and future onsite outdoor commercial/industrial workers and construction/trench workers potentially exposed to lead in onsite groundwater. The maximum concentration of lead detected above the laboratory reporting limit in onsite groundwater is 2.05 µg/L. The USEPA's threshold lead concentration of 10 µg/dL of whole blood is based on potentially adverse neurological effects in children (CDC 2011). The 95th percentile blood lead concentration (PbB) among fetuses of onsite adult workers, assuming potential exposure to the maximum detected concentration in onsite groundwater, was calculated using the ALM (USEPA 2009b). Using the groundwater ingestion rates and exposure frequencies for current and future onsite outdoor commercial/industrial workers and construction/trench workers presented in Table 3-12, the calculated probabilities that fetal PbBs are greater than10 µg/dL are 0.005 and 0.002%, respectively. Thus, potential exposures to lead in groundwater at the site are below the regulatory level of concern and are not expected to pose adverse health effects to current and future onsite outdoor commercial/industrial workers and construction/trench workers. The Calculations of Blood Lead Concentrations spreadsheet is provided in Appendix I.

Based on the results of the ALM (USEPA 2009b), the maximum detected concentration of lead in onsite groundwater is not expected to pose adverse health effects to current and future onsite outdoor commercial/industrial workers or construction/trench workers.

3.5 Uncertainty Assessment – PPRTV Scenario

Each exposure parameter value and toxicity value incorporated into the HHRA is associated with some degree of uncertainty; these uncertainties may contribute to an overestimation or underestimation of risks at the site (ADEC 2011c). Therefore, key uncertainties associated with each HHRA component (i.e., data evaluation, COPC selection, toxicity assessment, exposure assessment and risk/hazard characterization) were evaluated.

3.5.1 Data Evaluation

Soil and onsite groundwater samples were analyzed for a large suite of constituents from multiple samples collected throughout the site over time. These samples were analyzed using accepted analytical methodologies. It is unlikely that constituents were overlooked or underestimated by the analytical methods employed. The laboratory method used for soil sulfolane analyses in 2010 and 2011 was not final at the time, but the analytical results have been validated with an approved method.

The release-related constituents detected in soil (e.g., BTEX) were measured in more than 250 soil samples, of which 88 were surface soil samples. The large data set provides high confidence in the 95% UCL on the mean concentrations and in the representativeness of the use of this statistic for EPCs.

A large number of samples of key constituents detected at the site are available for use in the data evaluation. For example, for sulfolane in offsite groundwater, more than 429 samples were grouped by concentration ranges with each range having a high number of samples to represent that zone (i.e., 105 samples in the greater than 100 µg/L EU, 72 samples in the greater than 25 µg/L EU and 252 samples in the EU with detections up to 25 µg/L). The number of samples increases the representativeness of the EPCs based on these groupings of data and it is unlikely that the EPC based on the 95% UCL on the mean concentration underestimates potential exposures to sulfolane given the number of samples. The maximum detected concentration of sulfolane (443 µg/L) is 1.4 times higher than the next highest detection of sulfolane in offsite wells and 3 times greater than the 95% UCL on the mean concentration for the greater than 100 µg/L EU.

Data for onsite wells with multiple sampling rounds were averaged together and these temporal average well concentrations were grouped to calculate 95% UCL concentrations on the mean. Each temporal average concentration represents multiple sampling events and provides a reliable measure of constituent concentrations in that well. Grouping the data by well to estimate EPCs reduced the number of samples upon which the statistical analysis could be based. Where too few wells were available to reliably estimate 95% UCL values, the highest temporal well average was used to represent the EPC, which is an overestimate of potential exposure.

3.5.2 Constituent of Potential Concern Selection

COPCs were selected from a list of COIs known or suspected to have been used at the site. The approaches used to characterize the site were intended to identify the COPCs in environmental media associated with current and historical site operations. Sampling events were sequentially conducted based on the knowledge obtained from past sampling events. It is likely that these events identified the majority of areas with residual COPCs. While it is possible that some substances may have been omitted, the probability of those substances being important in driving risk is expected to be low. The suite of analyses that was selected represents those constituents that would most likely result from site operations and are therefore the most relevant and appropriate constituents for estimating risks and hazards. Note that analyses of isopropanol and propylene glycol were inadvertently missed during recent groundwater sampling events. Although the potential presence of these constituents is not expected to change the outcome of the risk evaluation, these COPCs will be evaluated once data have been collected.

3.5.3 Toxicity Assessment

Dose-response values are sometimes based on limited toxicological data. For this reason, a margin of safety is built into estimates of both carcinogenic and noncarcinogenic risk, and actual risks are lower than those estimated. The two major areas of uncertainty introduced in the dose-response assessment are: (1) animal to human extrapolation and (2) high to low dose extrapolation. These are discussed below.

Human dose-response values are often extrapolated, or estimated, using the results of animal studies. Extrapolation from animals to humans introduces a great deal of uncertainty in the risk assessment because in most instances, it is not known how differently a human may react to the constituent compared to the animal species used to test the constituent. The procedures used to extrapolate from animals to humans involve conservative assumptions and incorporate several uncertainty factors that overestimate the potential adverse effects associated with a specific dose. As a result, overestimation of the potential for adverse effects to humans is more likely than underestimation.

Predicting potential health effects from exposure to media containing COPCs requires the use of models to extrapolate the observed health effects from the high doses used in laboratory studies to the anticipated human health effects from low doses experienced in the environment. The models contain conservative assumptions to account for the large degree of uncertainty associated with this extrapolation (especially for potential carcinogenic effects) and therefore, tend to be more likely to overestimate than underestimate potential risks.

Oral RfDs for sulfolane have been derived using different approaches and laboratory studies. For the PPRTV Scenario, the USEPA (2012b) PPRTV chronic oral RfD of 0.001 mg/kg-day and PPRTV subchronic oral RfD of 0.01 mg/kg-day were used to derive HIs. In the ARCADIS Comparative Scenario, alternate chronic and subchronic RfDs of 0.01 mg/kg-day and 0.1 mg/kg-day that were derived by ARCADIS from scientific literature were used to derive HIs. As expected, with the alternate sulfolane oral RfD values, the HIs decrease. The reasoning for the ARCADIS derivation is provided in Section 4 and Appendices H and K.

3.5.4 Exposure Assessment

According to USEPA (2001) guidance, screening-level estimates of exposure and risk calculations use assumptions that maximize the estimate of risk to ensure that only those constituents that represent a *de minimis* risk are eliminated from further consideration, and those that potentially pose an unacceptable risk will be retained for consideration in subsequent steps of the risk assessment process. As requested by the ADEC, maximum concentrations of COPCs were used as EPCs in the risk calculations for the potential receptors evaluated for the PPRTV Scenario. More often, a conservative estimate of average concentrations of constituents is used to represent EPCs (USEPA 1989, 2002c, 2006b, 2007). Potential receptors are more likely to be exposed to a range of these concentrations represented by the average or 95% UCL concentration.

Concentrations of VOCs in indoor air of current and future onsite commercial/industrial structures were estimated using concentrations of VOCs in groundwater at the site. Due to the uncertainties associated with partitioning from soil to soil gas, ITRC (2007b) does not recommend using soil data as a source of COPCs to evaluate potential vapor intrusion. Thus, use of soil data to evaluate potential soil vapor concerns is inappropriate. USEPA (2002a) and ITRC (2007a) recommendations concluded that there is insufficient scientific support for this procedure. ITRC (2007a) notes "Scientific studies have failed to show good correlation between soil and soil gas sampling and analysis on a consistent basis." They conclude by recommending that soil data should be used only as a secondary line of evidence and not as a primary line. Overall, the scientific evidence indicates that use of soil data is not a reliable approach for identifying potential vapor intrusion concerns.

Dermal contact with COPCs in groundwater by current and future onsite outdoor commercial/industrial workers was considered an insignificant exposure pathway. Onsite use of groundwater beneath the site is limited to infrequent fire extinguishing. Fires at the site are very rare and the period of exposure would likely be relatively very short. Thus, exclusion of this potential exposure pathway would not significantly impact ELCR and HI estimates for these possible onsite receptors.

For the offsite CSM, it was assumed that groundwater may be connected with surface water, and pore-water data were collected to evaluate potentially complete exposure pathways for surface water. Pore-water piezometer installation methods needed to be revised for two of the three offsite locations because the surface-water body was frozen and pore-water samples could not be collected. However, the groundwater samples collected were able to be evaluated for human health risk. Because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water (ADHSS 2010), and given the limited groundwater-surface water interchange due to a frozen surface-water body, the groundwater collected adjacent to two of the three surface-water bodies in 2012 likely overestimates the surface water concentrations at those locations. Thus, the data used for the swimming scenario overestimate human health risk.

Ingestion of offsite groundwater by current and future offsite residents was the primary exposure pathway for these potential receptors and resulted in the relatively highest HIs, including for infants (0 to 1 year). The ingestion rate used for this age group slightly exceeded that used for children (0 to 6 years). It was also assumed that infants do not breastfeed and that their formula was made with tapwater instead of pediatrician-recommended distilled water. Thus, it is highly likely that HI estimates for this receptor were overestimated.

Only potential ingestion exposures were quantitatively assessed for sulfolane. This analysis suggests that dermal contact and inhalation exposure routes are not significant for sulfolane, which is supported by ATSDR (2010 and 2011) Health Consultations and animal studies (Brown et al. 1966, Andersen et al. 1977). Although these exposure routes were excluded, inclusion of them would likely not contribute significantly to overall hazard estimates. As described in Section 3.1.1.4, dermal contact and inhalation exposure routes are not significant for sulfolane. These assumptions are based on animal studies that have shown that sulfolane is not readily absorbed through human skin because of its low permeability and is not expected to pose a significant risk via an inhalation exposure route due to its low volatility. Ingestion of sulfolane in impacted environmental media is the appropriate exposure route to assess potential hazards to on and offsite receptors. Estimated hazards based on inhalation and dermal exposure routes are insignificant relative to hazards estimated based on the ingestion exposure route.

The ingestion rates of homegrown fruit and vegetables for offsite residents are not known. In the PPRTV Scenario, ingestion of fruit and vegetables by offsite residents was evaluated based on an assumed consumption rate equivalent to 95% of the population. As is described in the Uncertainty Assessment in Section 4, ARCADIS selected mean *per capita* ingestion rates.

HIs using the mean *per capita* ingestion rates would be approximately five times lower for the ingestion of produce exposure pathway. For the PPRTV Scenario, a groundwater-to-produce BCF value of 1 was assumed. HIs for the ingestion of homegrown produce pathway calculated using a BCF of 0.32 (the derivation of which is described in Section 4.5.4) would be approximately three times lower than the HIs calculated in the PPRTV Scenario. The cumulative impact of using both the mean per capita ingestion rates (factor of approximately 2.8) and a BCF of 0.32 (factor of approximately 3.1) result in HIs that are approximately nine times lower than the HIs calculated in the PPRTV Scenario. However, even using high end exposure and uptake assumptions for ingestion of homegrown produce, this is an insignificant exposure pathway compared to ingestion of groundwater.

In the PPRTV Scenario, swimming was assumed to occur 60 days per year for 1 hour per day with surface-water ingestion rates at the maximum ingestion rate for adults and the 97th percentile ingestion rate for children age 18 and under. HIs based on an EF of 30 days per year for 0.5 hour per day at recommended mean value ingestion rates (USEPA, 2011a), which are the exposure parameters selected by ARCADIS as described in the Uncertainty Assessment in Section 4, would be approximately ten times (a factor of 9.7) lower than those calculated for the PPRTV Scenario.

3.5.5 Risk/Hazard Characterization

Some HIs exceed the USEPA and the ADEC acceptable target HI equal to 1, particularly those estimated for onsite construction/worker exposures to volatile COPCs in the air of a trench, which have been modeled from groundwater concentrations. For this Revised Draft Final HHRA, endpoint-specific HIs were not calculated and summing all HQs regardless of endpoint is a health-protective approach. The USEPA acknowledges that adding all HQ or HI values may overestimate hazards, because the assumption of additivity is likely appropriate only for those chemicals that exert their toxicity by the same mechanism (USEPA 1989). Application of endpoint-specific HIs is expected to reduce total HI estimates.

The child scenario has been assessed in this section using the chronic oral reference dose, which is by definition a daily dose that is protective for sensitive receptors for lifetime exposures. Many USEPA programs such as the drinking water program use adult scenarios to protect both adults and children. For instance, Federal drinking water standards are derived using adult receptors, and USEPA states that such standards are protective for both adults and children. The use of the child exposure levels and body weights coupled with a chronic reference dose in this section provides an additional margin of exposure, but it is uncertain whether it provides additional public health protection. Appendices H and K provide additional information on sulfolane's toxicological profile. These documents show that sulfolane presents no special concerns to children, and that focusing public health protection efforts on adult receptors using a chronic reference dose adequately protects children.

4. ARCADIS Comparative Scenario

This section presents the ARCADIS Comparative Scenario estimated ELCRs and HIs for the same potentially complete and significant exposure pathways identified in Section 3.1.1.4 for the same potential receptors located on and offsite. In this section, the toxicity value for sulfolane that was selected by ARCADIS, as described in Appendix H, is used, with the same exposure parameters presented in Table 3-12. For each total estimated ELCR and HI, the primary exposure pathway and COPC(s) are indicated, as appropriate. In the ARCADIS Comparative Scenario, chronic oral RfDs were used to evaluate child exposures. Child and subchronic oral reference doses were used to evaluate child exposures in the ARCADIS Scenario, presented in the Uncertainty Assessment (Section 4.5.4) Supportive reasoning for these choices is provided in Appendices H and K.

4.1 Exposure Assessment

ARCADIS conducted an HHRA to evaluate the potential for human health risk from exposure to site-related constituents, following protocols presented in the June 8, 2000 ADEC Risk Assessment Procedures Manual that are adopted into regulation in 18 AAC 75. The primary ADEC references for this Revised Draft Final HHRA include the Draft Risk Assessment Procedures Manual (ADEC 2010a and 2011d), Cleanup Levels Guidance (ADEC 2008a), Cumulative Risk Guidance (ADEC 2008b), and 18 AAC 75 Oil and Other Hazardous Substances Pollution Control guidance (ADEC 2008c). Other references used include RAGS (USEPA 1989, 1991, 2001, 2004a and 2009a), Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (USEPA 2002a), Vapor Intrusion Pathway: A Practical Guide (ITRC 2007a) and Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios (ITRC 2007b).

4.1.1 Human Health Conceptual Site Models

Two preliminary human health CSMs (one onsite CSM and one offsite CSM) were prepared and submitted to the ADEC with the Site Characterization Work Plan (Barr 2010b). After this submittal, a substantial amount of additional site assessment data was collected and in April 2011 the updated CSMs were submitted to the ADEC to reflect the enhanced understanding of site conditions. In the RAWP submitted to ADEC in December 2011 (ARCADIS 2011a), the CSMs were further refined to better reflect existing site conditions. The updated CSMs were developed following the Human Health Conceptual Site Model Graphic and Scoping Forms and the Policy Guidance on Developing Conceptual Site Models (ADEC 2010b and 2010c, respectively). Due to the significant difference in COPC occurrence onsite (petroleum hydrocarbon constituents and sulfolane) versus offsite (sulfolane only), two human health CSM graphic forms (Figures 3-1 and 3-2) were prepared and updated to more clearly portray and distinguish potential exposure pathways for possible on- and offsite receptors.

This section describes the CSMs submitted to the ADEC in December 2011 and revisions to the offsite CSM based on ADEC comments discussed during the meeting held on January 24, 2012. Human health CSMs for on- and offsite locations are presented on Figures 3-1 and 3-2, respectively, and are discussed in the following subsections.

4.1.1.1 Potential Sources

During site operations, various materials associated with the crude oil refining process have been released in operating areas of the site, including the crude oil processing units, extraction unit, loading racks, wastewater lagoons, sumps and drain systems. In addition, spills and/or leaks to surface soil from ASTs, pumps and associated piping during routine operations constitute potential sources of petroleum constituents at the site. Petroleum hydrocarbons have also been detected in historical groundwater samples collected from onsite monitoring wells.

Onsite impacted environmental media may include surface (0 to 2 feet bgs) and subsurface (to a depth of 15 feet bgs, the maximum depth at which human exposure is likely to occur) soil, groundwater, indoor and outdoor air, surface water, sediment and biota. Offsite impacted media may include groundwater, surface water, sediment, wild food (such as fish) and homegrown produce.

4.1.1.2 Potential Fate and Transport Mechanisms

As described in Section 4.1.1.1, the primary sources of COPCs are spills and releases to soil and groundwater during facility operations. COPCs may be retained in site soils or subject to constituent fate and transport mechanisms at the site. Fate and transport mechanisms may include soil sorption; biodegradation; wind erosion and transport; migration to groundwater; advective/dispersive transport in groundwater, on or offsite; and volatilization into soil gas, outdoor air or indoor air.

Potential current and future onsite receptors may be directly exposed to COPCs in surface and subsurface soil via incidental ingestion, dermal contact and inhalation of dust particles in air. In addition, COPCs adhered onto dust particles may migrate from exposed surface or subsurface soil to outdoor air and be breathed by potential offsite receptors. When bound to surface soils, compounds sorbed to soil particles may be subject to wind erosion and windblown transport in outdoor air. Due to the nature of the site, the majority of operational areas are covered with asphalt pavement or gravel. However, exposed and unpaved areas do exist at the site. Therefore, although limited, windborne particulate transport is possible at the site, and this potential pathway was evaluated during the HHRA.

COPCs may leach from soil to groundwater by percolation or may have been directly released to groundwater. Based on groundwater samples collected from onsite wells, sulfolane is the only COPC that is known to have migrated offsite. Potential direct-contact exposures to COPCs in groundwater (e.g., tapwater ingestion and inhalation of volatiles in water) are not expected to occur for current and future onsite commercial/industrial workers because onsite groundwater is only used for industrial purposes (e.g., fire suppression). However, current and future onsite outdoor commercial/industrial receptors may be exposed to COPCs in groundwater by dermal contact while extinguishing fires, if they occur. In addition, due to the relatively shallow average depth to groundwater onsite (historically from 8 to 10 feet bgs), current and future onsite construction/trench workers may be exposed by incidental ingestion of and dermal contact with COPCs in groundwater that has pooled in excavated trenches.

The city provides municipal water for drinking and other potable uses at the site. Current onsite receptors consume drinking water from a municipal source and are expected to consume drinking water from this source in the future. Current and future offsite receptors may be exposed to sulfolane in groundwater that has migrated from the site to wells used for tapwater. In addition, groundwater may be used offsite to irrigate homegrown produce. Sulfolane in groundwater may be taken up by homegrown produce and consumed by offsite residents.

Onsite surface water consists of water that is stored in two lagoons and two gravel pits. Runoff and erosion from soil to surface water may be transport mechanisms. Groundwater from the site flows offsite in a north-northwesterly direction and groundwater is recharged by surface water from the Tanana River. COPCs in groundwater may eventually flow to offsite surface-water bodies and to sediment, which may be contacted by offsite recreational users. Pore-water data were collected to evaluate the potential for exposure at the groundwater/surface-water interface. Some of the samples used for this HHRA were collected when the adjacent surface-water body was frozen; therefore, the degree of connectivity with the surface water, if any, could not be established.

For this HHRA, potential ingestion of sulfolane in surface water by adult and child recreational users while swimming is considered a potentially complete exposure pathway offsite. The collected pore-water samples likely reflect higher sulfolane concentrations than would be expected in true pore-water samples because of limited surface water to groundwater interchange during frozen conditions. Pore-water samples will generally reflect higher sulfolane concentrations than would be encountered by actual recreational users of the surface water bodies because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water (ADHSS 2010). Accordingly, the data presented in this Revised Draft Final HHRA provide a health-protective assessment of risk to swimmers.

Volatilization is another fate and transport mechanism at the site for lighter petroleum hydrocarbon compounds and other VOCs. VOCs may volatilize from subsurface soil into soil gas, with eventual diffusion and/or advection into outdoor air and/or indoor air in onsite buildings. VOCs may also leach from soil to groundwater, where dissolved-phase VOCs may be transported downgradient both on and offsite. VOCs may volatilize from shallow exposed groundwater in excavations directly into outdoor air. VOCs may volatilize from groundwater into soil gas, with eventual diffusion and/or advection into outdoor air and/or indoor air of on- and/or offsite buildings. VOCs may also be subject to degradation by microorganisms in subsurface soils and groundwater. Heavier petroleum hydrocarbon compounds, such as PAHs, adsorb to solids and do not tend to volatilize. As such, these compounds generally tend to remain in place, where they are subject to aerobic biodegradation by microorganisms. Sulfolane is not expected to volatilize under the conditions observed at the site, as discussed in Section 4.1.1.4.

4.1.1.3 Potential Receptors

Potential human receptors were identified based on current and reasonably foreseeable future land use at the site. A review of current and future land use identified the following potential human receptors at the site.

- **Current and future onsite indoor commercial/industrial workers** were considered to be individuals from 18 to 65 years old. It was assumed that these receptors perform commercial and/or industrial work activities (e.g., office work, laboratory analyses, shipping or warehouse inventory management) indoors onsite, under current or future (redeveloped) land use scenarios. Potential exposures to COPCs in soil are considered to be insignificant for onsite indoor commercial/industrial workers. These potential receptors may be exposed to COPCs in indoor air during a standard 40-hour work week for 25 years, for 250 days per year. Potential inhalation of outdoor air is insignificant. Inhalation of VOCs in indoor air was evaluated following USEPA (2009a) RAGS Part F.

- **Current and future onsite outdoor commercial/industrial workers** were considered to be individuals from 18 to 65 years old. These receptors were assumed to perform commercial and/or industrial work activities (e.g., maintenance work for ASTs or associated piping) outdoors at the site under current or future (redeveloped) land use scenarios. These individuals may occasionally use site groundwater for industrial purposes (e.g., fire suppression). Direct-contact exposures with groundwater are considered insignificant because fires are rare onsite and the exposure period is expected to be short. This exposure pathway was not quantitatively evaluated. These potential receptors may be exposed to COPCs in site media during a standard 40-hour work week for 25 years, for 250 days per year. Following ADEC (2010a) guidance, it was assumed that onsite outdoor workers with an average BW of 70 kg are exposed to 100 mg/day COPCs in surface soil and that 100 percent of the FI is from onsite surface soil.

  FHRA requires all onsite workers to wear long-sleeved shirts, long pants and shoes. Thus, the adult commercial/industrial worker outdoor receptor was assumed to wear a long-sleeved shirt, long pants and shoes, which limits the exposed skin surface to the head and hands. The recommended USEPA (2011a) SSA exposed to impacted soil for the adult commercial/industrial worker outdoor receptor is 2,230 cm^2, which is the average of the adult male and adult female mean values for head and hands. The USEPA (2004a) recommended weighted soil-to-skin AF for a commercial/industrial adult worker of

0.2 mg/cm^2 based on the 50th percentile weighted AF for utility workers (i.e., the activity determined to represent a high-end contact activity) was used. Potential inhalation of indoor air was considered insignificant for the outdoor commercial/industrial worker. Inhalation of volatile COPCs and dust in outdoor air was evaluated following USEPA (2009a) RAGS Part F.

- **Current and future onsite construction/trench workers** were considered to be individuals from 18 to 65 years old. These receptors were assumed to perform short-term maintenance and emergency repair activities on underground utilities or facility piping at the site. These receptors may be exposed to COPCs in surface and/or subsurface soil during the work day while performing the maintenance and/or repair task. Because the depth to groundwater at the site generally ranges from 8 to 10 feet bgs, construction/trench workers may be exposed to COPCs in groundwater that has pooled in a trench during performance of the maintenance and/or repair task. It was assumed that the same worker will provide maintenance and/or repair tasks.

  Potential construction/trench worker receptors were assumed to be exposed to COPCs in onsite soil (down to a depth of 15 feet bgs) and groundwater for 1 hour each day of a standard 5-day work week, for 125 days, for 1 year. This EF is a modification from that proposed in the RAWP (250 days per year). This deviation is justified because most of the utilities at the site are located aboveground and trenching activities typically do not occur during 6 months of each year, when the ground is frozen. It is assumed that soil may be accessible for trenching activities (i.e., not frozen) for 6 months per year.

  Construction/trench workers with an average BW of 70 kg are assumed to be exposed to 330 mg/day (USEPA 2002b) of COPCs in surface and subsurface soil, and 100 percent of the FI is assumed to be from surface and subsurface soil. It was assumed that onsite construction/trench workers incidentally ingest 0.0037 L/day of groundwater pooled in a trench. This rate is based on the mean ingestion rate for wading/splashing presented in the USEPA (2011a) EFH Table 3-93 (3.7 milliliters per hour * 1 hour per day). This consumption rate is likely to overestimate actual exposure, because dewatering usually occurs at excavation sites where water has pooled in trenches.

  FHRA requires all onsite workers to wear long-sleeved shirts, long pants and shoes. Therefore, the onsite adult construction worker receptor was assumed to wear a long-sleeved shirt, long pants and shoes, and the exposed SSA was limited to the head and hands. The USEPA (2011a) recommended SSA exposed to impacted soil for the adult construction worker receptor is 2,230 cm^2. The USEPA (2002b) recommended weighted soil-to-skin AF for a construction worker of 0.3 mg/cm^2-day was used. Inhalation of volatile COPCs and dust in outdoor air were evaluated following USEPA (2009a) RAGS Part F.

- **Current and future onsite visitors and trespassers.** Occasional visitors or trespassers may also be present onsite. However, the site does not and is not expected to attract trespassers because of the character and location of the site (i.e., an industrial setting with controlled access). Moreover, it is anticipated that a trespasser's exposure at the site would be very infrequent. Onsite visitors are typically adults with limited access across the site. Children rarely visit the site. Thus, potential direct-contact exposures to COPCs in soil and groundwater by current and future onsite trespassers and visitors are insignificant. Potential inhalation of outdoor air is also insignificant. However, assuming the adult visitor is located in an onsite building, inhalation of volatile COPCs in indoor air by this potential receptor was evaluated following USEPA (2009a) RAGS Part F. Current and future onsite adult visitors (18 to 65 years of age) are assumed to be exposed to COPCs in indoor air for 2 hours per day, 12 days per year for 30 years.

- **Current and future offsite residents** were evaluated as infants (0 to 1 year of age), children (1 to 6 years of age) and adults (18 to 65 years of age). HHRAs do not typically focus on infant exposures as a separate receptor group, but infants are included here because the ATSDR (2011) and the ADHSS (2012) have addressed infants as a separate receptor group in their Health Consultations. There is evidence that sulfolane does not present a significant risk for developmental effects and it is not mutagenic, mitigating infant-specific exposure concerns. Resident receptors were assumed to be located downgradient of the site and may be exposed to sulfolane in groundwater that has migrated from the site. No other COPCs associated with site operations are known to be present in offsite groundwater. These potential offsite receptors may ingest sulfolane in groundwater as tapwater. In addition, it was assumed that these potential receptors consume homegrown produce, which may have taken up sulfolane from groundwater. It was assumed that potential resident receptors may be exposed to sulfolane in tapwater for a 1-, 6- and 30-year duration for infants, children and adults, respectively, for 350 days per year.

  Current and future offsite adult, child and infant residents may also inhale dust from the site. Inhalation of dust in outdoor air by these potential receptors was evaluated following USEPA (2009a) RAGS Part F.

  Following ADEC (2010a) guidance, it was assumed that 70 kg adult residents consume 2 L/day of tapwater. Following USEPA (1989) guidance, it was assumed that 15 kg child residents consume 1 L/day of tapwater. Infants were assumed to weigh an average of 6.75 kg (the average of the age-group specific mean values from 0 to 1 year) and to consume 1.05 L/day (the time-weighted average of the *per capita* age-group-specific 95th percentile values from 0 to 1 year) of tapwater based on USEPA (2011a) guidance. The groundwater ingestion exposure parameters for infants likely overestimate potential exposure because it was assumed that they do not breastfeed and do not consume formula made with distilled water (a typical pediatric guideline for the first several months of life).

Fractions of homegrown fruit and vegetables ingested, water-to-produce BCFs and ingestion rates for offsite adult and child residents for the ARCADIS Comparative Scenario are discussed in Section 4.1.3.1.6.

- **Current and future offsite indoor and outdoor commercial/industrial workers** were considered to be individuals from 18 to 65 years old. It was assumed that these potential receptors perform commercial and/or industrial work activities indoors or outdoors at offsite locations under current or future land use scenarios during a standard 40-hour work week for 25 years, for 250 days per year. These receptors may ingest sulfolane in groundwater as tapwater. Following ADEC (2010a) guidance, it was assumed that 70 kg offsite adult commercial/industrial workers consume 2 L/day of tapwater. In addition, they may inhale dust that may have been released onsite via wind erosion. Potential exposures to COPCs in dust were considered to be insignificant for offsite indoor commercial/industrial workers. Inhalation of dust in outdoor air by outdoor commercial/industrial workers was evaluated following USEPA (2009a) RAGS Part F.

- **Current and future offsite recreational users.** Sulfolane may potentially migrate offsite via groundwater to surface water and to sediment in downgradient surface-water bodies. Access to downgradient, offsite surface-water bodies is minimal due to surrounding industrial land use and hazardous physical conditions, and direct contact with surface water and sediment by human receptors is limited. Regardless, for this HHRA, ingestion of surface water by offsite adult and child recreational users while swimming is considered a potentially complete exposure pathway. Recreational user exposure assumptions for the ARCADIS Comparative scenario are discussed in Section 4.1.3.3.

- **Current and future offsite construction/trench workers** were considered to be individuals from 18 to 65 years old. These receptors were assumed to perform short-term maintenance and emergency repair activities on underground utilities at offsite properties. These potential receptors may be exposed to sulfolane in groundwater that has pooled in a trench during performance of the maintenance and/or repair task. It was assumed that offsite construction/trench workers incidentally ingest 0.0037 L/day of groundwater pooled in a trench. This rate is based on the mean ingestion rate for wading/splashing presented in the USEPA (2011a) EFH Table 3-93 (3.7 milliliters per hour * 1 hour per day). This consumption rate is conservative, because dewatering usually occurs at excavation sites where water has pooled in trenches. It was conservatively assumed that the same worker performs multiple maintenance and/or repair tasks. These potential receptors (70 kg for adults) may be exposed to sulfolane in groundwater for 1 hour each day of a standard 5-day work week, for 125 days per year, for 1 year.

4.1.1.4 Exposure Pathway Evaluation.

Potential exposure pathways selected for quantitative evaluation are shown in the on- and offsite human health CSMs. An exposure pathway was retained for further evaluation if it was considered potentially complete. Each of the following components must be present in order for an exposure pathway to be considered complete (USEPA 1989):

- Source and/or constituent release mechanism
- Retention or transport medium
- Receptor at a point of potential exposure
- Exposure route at the exposure point.

Complete exposure pathways were evaluated for identified COPCs. Only potential ingestion exposures were quantitatively assessed for sulfolane. Dermal contact and inhalation exposure routes are not significant for sulfolane. The ATSDR (2010 and 2011) Health Consultations support these conclusions. Animal studies have shown that sulfolane is not readily absorbed through human skin because of its low permeability (Brown et al. 1966) and is not expected to pose a significant risk via an inhalation exposure route due to its low volatility (Andersen et al. 1977). Brown et al. (1966) studied the skin and eye irritant and skin sensitizing properties of acute exposures to sulfolane on two animal species. This study concluded that sulfolane did not irritate or sensitize the skins of guinea pigs or rabbits and, undiluted, was only very mildly irritating on the eyes of rabbits.

Andersen et al. (1977) conducted acute and subacute investigations of the inhalation toxicity of sulfolane on four animal species including monkey, dog, guinea pig and rat. A no-observed-effect level for sulfolane of 20 mg/m^3 was reported, and the authors concluded that airborne concentrations of sulfolane as high as those investigated are unlikely to be encountered on any but an emergency basis. Andersen et al. (1977) reported that sulfolane has a relatively low vapor pressure (approximately 0.13 millimeter of mercury at 32 °C and only unusual conditions would produce an extensive release of aerosolized sulfolane. Andersen et al. (1977) further noted that if sulfolane is handled at room temperature in an area with proper ventilation, it should not be regarded as posing an unusual hazard.

Potentially complete and significant exposure pathways were identified for the following receptors, with the exception that dermal and inhalation exposures to sulfolane are incomplete (as noted above):

- Onsite indoor commercial/industrial worker (current and future):
  - Inhalation of volatile COPC vapors in indoor air from groundwater.
- Onsite outdoor commercial/industrial worker (current and future):

- Ingestion of, dermal contact with and inhalation (particulates) of COPCs in surface soil.
- Dermal contact with COPCs in groundwater while extinguishing fires was qualitatively evaluated.
- Inhalation of volatile COPC vapors in outdoor air volatilized from surface and subsurface soil and groundwater.

- Onsite construction/trench worker (current and future):
  - Ingestion of, dermal contact with and inhalation (particulates) of COPCs in surface and subsurface soil.
  - Inhalation of volatile COPC vapors in trench air from surface and subsurface soil and groundwater.
  - Ingestion of and dermal contact with COPCs in groundwater in excavation trenches.
- Onsite adult visitor (current and future):
  - Inhalation of volatile COPC vapors in indoor air from groundwater.
- Offsite adult, child and infant residents (current and future):
  - Ingestion of sulfolane in groundwater (i.e., tapwater).
  - Ingestion of homegrown produce irrigated with sulfolane-impacted groundwater.
  - Inhalation of fugitive windborne dust from onsite COPCs in surface soil.
- Offsite indoor and outdoor commercial/industrial worker (current and future):
  - Ingestion of sulfolane in groundwater (i.e., tapwater).
  - Inhalation of fugitive windborne dust from onsite COPCs in surface soil (outdoor worker only).
- Offsite construction/trench worker (current and future):
  - Ingestion of sulfolane in groundwater (i.e., in excavation trenches).
- Offsite adult and child recreational users (current and future):

- Ingestion of sulfolane in surface water (i.e., pore water).

4.1.2 Data Evaluation, Constituent of Potential Concern Selection and Identification of Data Gaps

The proposed methods for data evaluation, identification of data gaps, selection of COPCs and proposed sampling to address data gaps are discussed below. Both maximum and 95% UCL on the mean constituent concentrations for groundwater were evaluated.

4.1.2.1 Data Evaluation

The available data that were used include analytical results from soil investigations conducted at the site since 2001. Data from four sets of soil samples were evaluated, including samples collected in March and May 2001, July 2004, October 2010 and October 2011. One soil sample collected in 2010 (O-2 [7.5-9]) was determined to be unusable in a Level four data validation, so this sample was not included in EPC calculations.

Groundwater and surface-water data collected during the last two years were also included. SWI provided the soil and groundwater analytical data used in the HHRA in an electronic format. Initially, the data were separated into individual datasets by environmental media, including: onsite groundwater, offsite (downgradient) groundwater, onsite surface soil (0 to 2 feet bgs) and onsite subsurface soil (2 to 15 feet bgs).

The quality of the data is acceptable for risk assessment use. Parameters evaluated in the data quality assessment include spatial and vertical coverage and representativeness of sampling locations, analytical methods and reporting limits used by the laboratories, and data qualifiers applied during data validation. The HHRA relies on validated data supplied by SWI as presented in the Revised Site Characterization Report (Barr 2012). Data collected for this evaluation were collected per ADEC-approved sampling and analysis plans. Consideration was given to the recently developed standard procedure for analyzing sulfolane in groundwater (isotope dilution) and the historical variability between analytical results. The data relied upon in this risk assessment met the following criteria for data usability for risk assessment as recommended in ADEC (2010a) guidance:

- Analytical data sufficient for adequate site characterization were available.
- Data were collected consistent with ADEC and USEPA guidance.
- Sampling and analytical procedures gave accurate constituent-specific concentrations.

- Level two data validation was performed on analytical laboratory data used for this evaluation. Validation reports for the 2011 soil and groundwater data, and for the 2012 pore-water data prepared by SWI, were included in the Revised Site Characterization Report (Barr 2012). Level four data validation was performed on the 2010 sulfolane in soil analyses.

- Method detection limits and sample quantitation limits were below screening criteria.

- Qualified data were used in the risk assessment; potential bias from qualified data and how it might result in an over or under estimation of risk is discussed in Section 4.5.

- Rejected data were not used for risk assessment purposes.

- For a given well, if all samples were reported as non-detects, then the lowest detection limit associated with any sampling event at that well was used to represent the well.

- If a well had both detected concentrations and reported non-detects for a given COPC, then the non-detect was represented by a value equal to one-half the detection limit associated with that COPC in that sampling event.

Offsite groundwater has been sampled at monitoring wells and private residential wells. At the request of ADEC, the off-site area was delineated into smaller EUs for the purposes of the 95% UCL evaluation. Accordingly, ARCADIS developed three separate EUs (e.g., EU-1, EU-2 and EU-3) for statistical evaluation. These EUs were based on estimated sulfolane isocontour lines developed from fourth quarter 2011 groundwater sampling data, and generally reflect spatially contiguous areas that represent certain ranges of concentration and portions of the sulfolane plume in groundwater. Some data points outside of the concentration range are present within each of the defined EUs and are the result of data collected from well screens of varying depths. These data points were included in the analysis, because it is reasonable to assume that any hypothetical exposures to water from drinking water wells within any given unit may also include exposures to groundwater generated at varying depths. The EUs are bounded by the concentration contours of greater than (>) 100 µg/L, >25 µg/L and detectable sulfolane (Figure 3-3). These contour intervals were selected and drawn using the combined offsite well data set and are based on best professional judgment. Guidance presented in the Data Quality Assessment: Statistical Methods for Practitioners (USEPA 2006a) was considered during selection of the off-site groundwater dataset(s). The data from wells within a given EU were used to estimate the 95% UCL on the mean concentration as a health-protective and representative EPC. ProUCL version 4.1 (USEPA 2011b) was used to derive the 95% UCL on the mean of the constituent concentrations.

The utility of the soil and groundwater analytical data identified in the SWI (2000 and 2001) contaminant characterization studies conducted for the site was evaluated for the HHRA. The characterization study conducted at the site in 2001 was performed to collect additional soil and groundwater data to address data gaps from the site investigation conducted in 2000. In general, for both media, the analytical methods used included those for GRO, DRO, RRO, BTEX, selected metals, VOCs, SVOCs and sulfolane (for groundwater only).

4.1.2.2 Constituents of Potential Concern

COPCs have been identified from a list of potential COIs, such as those that were likely used or spilled at the site. COPCs for each dataset were carried through the HHRA process.

Preliminary lists of COIs and COPCs in soil and groundwater at the site were presented in the Site Characterization and First Quarter 2011 Groundwater Monitoring Report (Barr 2011). The lists were revised in the Addendum (ARCADIS 2011b) based on the ADEC (2011a) Comment Matrix on the site characterization report. The lists of preliminary COIs and COPCs were also presented in the RAWP (ARCADIS 2011a).

As noted in the RAWP (ARCADIS 2011a), the list of COIs was developed according to the following process:

1. FHRA compiled a list of spills based on staff interviews, refinery records and a review of spill records retained by the ADEC.
2. The list of spills was refined by eliminating:
    a. Spills less than 10 gallons.
    b. Spills that were reportedly contained.
    c. Spills that were remediated and had confirmation sampling.

For many spills on the list, the material spilled was specific to one ingredient (e.g., propylene glycol) or was a material with obvious and limited ingredients (e.g., kerosene). However, the individual ingredients (e.g., oily water) of the other materials reportedly spilled were not provided. Refinery specialists such as chemists, wastewater experts and production leads were consulted to apply operational knowledge of the refinery to determine the ingredients that made up this set of materials. By this process, the list of spills was then distilled down to the "ingredients" or the primary constituents that make up the material spilled. This ingredient list was also compared to constituents that had been included in laboratory analyses of facility wastewater. The resulting ingredient list was then used to make up a list of COIs for the site. The COI list also included constituents that were analyzed during previous site characterization studies, regardless of whether they were detected above the PQL. The list of COIs for the site is shown in Table 3-1. Constituents in the ingredient list that were analyzed for but not detected were not removed from this list. If a constituent was previously detected at the site and/or was included in the ingredient list, it was considered a COI.

Table 3-1 indicates if a constituent was previously analyzed in soil or groundwater samples collected at the site. Table 3-1 also indicates if a constituent was included in the ingredient list; the last four columns of the table summarize whether toxicity data are available from the IRIS (USEPA 2012a).

For this Revised Draft Final HHRA, maximum detected concentrations and/or the laboratory reporting limits of COIs in soil and groundwater are compared with ADEC screening levels corresponding to a 1×10^{-6} target ELCR and 0.1 target HQ, as shown in Table 3-2a. COI soil concentrations were compared with ADEC screening levels protective of potential migration to groundwater based on a zone with less than 40 inches of annual precipitation, direct-contact exposures and outdoor inhalation (ADEC 2008a [Table B-1 of 18 AAC 75, Method Two]). If ADEC soil screening levels were unavailable, then COI concentrations in soil were compared with USEPA RSLs (USEPA 2011c), adjusted to a target ELCR of 1×10^{-6} (if necessary) and a HQ equal to 0.1, for the applicable exposure pathway. Soil screening levels for GRO, DRO and RRO were from ADEC (2008a) Table B-2 Method Two. COI groundwater concentrations were compared with ADEC groundwater screening levels (ADEC 2008a; Table C). If ADEC groundwater screening levels were unavailable, then COI concentrations were compared with USEPA RSLs (USEPA 2011c) based on tapwater ingestion.

The higher of either the maximum COI concentration detected above the laboratory reporting limit or maximum detection limit was compared with the selected ADEC screening levels. The selected soil screening levels were based on the lesser of the migration to groundwater, $^{1}/_{10}$ the direct contact or $^{1}/_{10}$ the outdoor air screening levels. COIs with concentrations exceeding the selected soil screening level were identified as COPCs. Table 3-2a lists the COPCs identified in soil and groundwater based on ADEC (2010a) COPC selection guidance applied to the COIs identified in Table 3-1.

The preliminary COPCs identified at the site, as presented in Table 3-2a, are COIs that were detected in site media and exceeded ADEC screening levels. COIs not detected in site media but that had practical quantitation limits exceeding ADEC screening levels and COIs identified by the refinery as ingredients that could have been released are also considered COPCs. Arsenic was eliminated as a COPC in groundwater based on published background concentrations for the area of the site (U.S. Geological Survey 2001). However, it was retained as a COPC in soil in the RAWP (ARCADIS 2011a). An evaluation of the 2011 arsenic in soil data was presented in the Revised Site Characterization Report (Barr 2012). Based on this evaluation, it is likely that the presence of detectable arsenic in soil samples collected at the site is attributable to background concentrations. No other metal COIs were eliminated from the list of COPCs based on background concentrations. In accordance with ADEC (2010a) guidance, Table 3-2a has been provided to the ADEC in Microsoft® Excel format.

Table 3-2b summarizes COPCs by environmental media.

4.1.2.3 Data Gaps

Based on a review of the preliminary human health CSMs and available analytical data for environmental samples collected at the site, and discussions held during the June 24, 2011 Risk Assessment Scoping Meeting, four potential risk assessment data gaps were indicated:

- Limited surface soil data were available for the evaluation of potential risks and hazards to onsite human receptors.
- Onsite containment of COPCs other than sulfolane must be supported.
- Possible connection between groundwater at the site and surface water must be determined.
- No soil gas data were available to evaluate onsite vapor intrusion concerns.

4.1.2.4 Sampling Plans to Address Data Gaps

Sampling plans for additional data collection are described in the Addendum (ARCADIS 2011b). With respect to risk assessment data gaps identified in Section 3.1.2.3, the following field activities have been conducted:

- Onsite soil assessment activities, to characterize soil impacts and provide data for risk assessment activities. The soil data collected in 2011 adequately characterized the nature and extent of surface and subsurface impacts for the purposes of this HHRA evaluation. Additional sampling is planned for 2012 to complete characterization for the purposes of a remediation feasibility study. The 2011 soil data were validated and included in this evaluation.
- Additional groundwater sampling, during the third and fourth quarters 2011, confirmed that no other COPCs (except sulfolane) have migrated offsite.
- A pore-water investigation was conducted to better characterize sulfolane concentrations in the groundwater/surface-water interface and the potential for surface-water sulfolane impacts. The March 2012 samples were collected when the adjacent surface-water body was frozen; therefore, the degree of connectivity with surface water, if any, could not be established. Therefore, the piezometer samples were likely more representative of groundwater. Because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water (ADHSS 2010), and given the limited groundwater-surface water interchange adjacent to a frozen surface-water body, the groundwater collected adjacent to two of the three surface-water bodies in 2012 likely overestimates the

surface water concentrations at those locations. The data presented in this Revised Draft Final HHRA provide a health-protective estimate of risk to swimmers.

Soil gas data were not collected to evaluate potential vapor intrusion concerns. Instead, onsite groundwater data were used to evaluate the vapor intrusion exposure pathway. All onsite groundwater analytical data collected during the last 2 years (2009 through 2011) were used to predict indoor air concentrations of volatile COPCs and to estimate risks and hazards to current and future onsite indoor commercial workers. The maximum detected groundwater concentration for each COPC was used as the source term for J&E groundwater-to-indoor air modeling (USEPA 2004b) in the maximum exposure scenario. The 95% UCL concentration calculated from the average concentration in each onsite well was used as the source term in the 95% UCL scenario.

4.1.3 Quantification of Exposure

The objective of the exposure assessment was to estimate the type and magnitude of potential receptor exposure to COPCs. Results of the exposure assessment were then combined with constituent-specific toxicity values in the toxicity assessment (see Section 4.2) to characterize potential risks (USEPA 1989).

4.1.3.1 Dose/Intake Equations

Exposures were quantified using standard exposure equations consistent with RAGS (USEPA 1989, 1991, 2004a and 2009a) for the potentially complete exposure pathways identified in Section 4.1.1.4.

The general algorithms presented below were used to estimate the LADD for carcinogenic compounds and the ADD for noncarcinogenic COPCs for direct-contact pathways (i.e., ingestion and dermal contact) by combining environmental media concentrations with the receptor-specific exposure parameters that constitute "intake factors." Both the ADD and the LADD are in units of mg/kg-day (USEPA 1989). For inhalation exposure pathways, exposure was estimated as an AEC for noncarcinogenic COPCs or LAEC for carcinogenic COPCs. Both the AEC and the LAEC are in units of mg/m^3 (USEPA 2009a).

The dose equations and parameter descriptions used are provided in the following subsections.

4.1.3.1.1 Incidental Ingestion of Soil

The doses of COPCs associated with incidental ingestion of soil were calculated as follows:

$$\text{Dose} = \underline{EPC_s * IR_s * FI * EF * ED * CF} \quad * RAF$$

BW * AT

Where:

Dose = ADD or LADD (mg/kg-day)

EPC_s = EPC in soil (mg/kg)

IR_s = soil ingestion rate (milligrams soil per day)

FI = fraction ingested (unitless)

EF = exposure frequency (days per year)

ED = exposure duration (years)

CF = conversion factor ($1x10^{-6}$ kg/mg)

BW = body weight (kg)

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

RAF = relative absorption factor (unitless), assumed to equal 1

The USEPA (1989) defines FI as a "pathway-specific" value that should be applied to consider constituent location and population activity patterns. FI accounts for the fraction of the site covered with asphalt or vegetation, which reduces potential exposure. Following the ADEC's (2010a) guidance, an FI of 1 was assumed for the current and future onsite outdoor commercial/industrial worker and future onsite construction/trench worker to provide a health-protective estimate of risk.

4.1.3.1.2 Dermal Contact with Soil

Absorbed doses of constituents associated with dermal contact with soil were calculated as follows:

$$\text{Dose} = \frac{EPC_s * SSA_s * AF * FC * ABS_d * EV_s * EF * ED * CF}{BW * AT}$$

Where:

Dose = ADD or LADD (mg/kg-day)

EPC_s = EPC in soil (mg/kg)

SSA_s = SSA available for contact (cm^2/event)

AF = soil-to-skin adherence factor (mg/cm^2-event)

FC = fraction in contact with soil (unitless)

ABS_d = dermal absorption factor (unitless)

EV_s = event frequency (soil) (events/day), assumed to be 1 per day unless otherwise noted

EF = exposure frequency (days/year)

ED = exposure duration (years)

CF = conversion factor (1×10^{-6} kg/mg)

BW = body weight (kg)

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

Constituent-specific dermal parameters, such as SSA_s, AF and ABS_d were provided from USEPA (2004a) RAGS Part E. ABS_d are presented in Table 3-13.

Similar to FI for the soil ingestion pathway, FC was added to the dermal contact equation to account for the fraction of the site covered with asphalt or vegetation, which reduces potential exposure. Following the ADEC's (2010a) guidance, an FC of 1 was assumed for the current and future onsite commercial/industrial worker and future onsite construction/trench worker to provide a health-protective estimate of risk.

4.1.3.1.3 Ingestion of Groundwater

The doses of COPCs associated with ingestion of groundwater were calculated as follows:

$$\text{Dose} = \frac{EPC_w * IR_w * EF * ED}{BW * AT}$$

Where:

Dose = ADD or LADD (mg/kg-day)

EPC_w = EPC in water (mg/L)

IR_w = water ingestion rate (liters water/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight (kg)

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

4.1.3.1.4 Dermal Contact with Groundwater

Absorbed doses of constituents associated with dermal contact with groundwater were calculated as follows:

$$\text{Dose} = \frac{DA_{event} * SSA_w * EV_w * EF * ED}{BW * AT}$$

Where for organics ($t_{event} \leq t^*$):

$$DA_{event} = 2 * FA * K_p * EPC_w * CF * \sqrt{\frac{6 * \tau_{event} * t_{event}}{\pi}}$$

Where for organics ($t_{event} > t^*$):

$$DA_{event} = FA * K_p * EPC_w * CF * \left[\left(\frac{t_{event}}{(1+B)} \right) + \left(2\tau_{event} \left[\frac{1+3B+3B^2}{(1+B)^2} \right] \right) \right]$$

Where for inorganics:

$$DA_{event} = K_p * EPC_w * CF * t_{event}$$

Dose = ADD or LADD (mg/kg-day)

DA_{event} = dose per event (mg/cm^2-event)

SSA_w = SSA available for contact with water (cm^2/event)

EV_w = event frequency (water) (events/day), assumed to be 1 per day unless otherwise noted

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight (kg)

t* = time to reach steady state (hours), equivalent to 2.4 x τ_{event}

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

FA = fraction absorbed (unitless)

K_p = permeability coefficient (centimeter/hour)

EPC_w = EPC in water (mg/L)

CF = conversion factor (1x10^{-3} liters per cubic centimeter)

τ_{event} = lag time per event (hours/event)

B = permeability ratio (unitless)

t_{event} = event duration (hours/event)

4.1.3.1.5 Inhalation of Outdoor or Indoor Air

Exposure concentrations associated with the inhalation of vapors or particulates in outdoor or indoor air are calculated using USEPA (2009a) RAGS Part F methodology as follows:

$$\text{AEC or LAEC} = \frac{EPC_a * EF * ED * ET}{AT}$$

Where:

AEC or LAEC = average or lifetime exposure concentration in air ($\mu g/m^3$)

EPC_a = EPC in outdoor or indoor air ($\mu g/m^3$)

EF = exposure frequency (days/year)

ED = exposure duration (years)

ET = exposure time (hours/day)

AT = averaging time (hours), for carcinogens is equal to 70 years * 365 days per year * 24 hours per day, and for noncarcinogens AT is equal to ED (in years) * 365 days per year * 24 hours per day

4.1.3.1.6 Ingestion of Homegrown Produce

Groundwater from the site may be used to irrigate locally grown crops, creating the potential for sulfolane to be taken up into plants that are then consumed by humans. In the few studies that have been conducted on the topic of uptake in plants, sulfolane has been demonstrated to be taken up into plants as the result of the constituent's high miscibility with water. Sulfolane is carried, along with water, through the roots, into the xylem and ultimately into the leaves of the plants. When water is lost through the leaves due to evapotranspiration, the sulfolane, due to its low volatility, tends to remain in the leaves where it may accumulate. Based on this information, it is assumed that if sulfolane is taken up by plants, it would predominantly be present in the leaves rather than in the roots or fruit.

This assumption is corroborated by the Final Results of the North Pole Garden Sampling Project (ADEC 2011b), which demonstrated that concentrations in roots were substantially lower than those in the stems and leaves. In the ADEC (2011b) study, which was led by ADHSS, 27 types of plant parts from multiple gardens irrigated with sulfolane-containing groundwater were collected from July to September 2010. Approximately one-half of the plant samples were reported as not detected, but 14 of the plant types tested were confirmed to contain sulfolane, primarily in the leaves and stems. Using data from the Final Results of the North Pole Garden Sampling Project (ADEC 2011b), the ADHSS evaluated the potential for risk to consumers of vegetables irrigated with sulfolane-containing water and concluded that sulfolane levels in the plants were low and not likely to cause any adverse health effects. However, because of the limited number of gardens sampled and the fact that the data were collected during only one growing season, the results of the investigation were considered preliminary and the exposure pathway was further evaluated in this assessment.

Following USEPA (2005) guidance, bioaccumulation of sulfolane in locally grown crops was evaluated using a biotransfer factor to estimate concentrations in plant tissues based on groundwater concentrations. There are no accepted values developed for sulfolane, but there is evidence to suggest that the uptake of sulfolane does not follow standard models based on partitioning coefficients (e.g., K_{ow}); therefore, an appropriate surrogate was not identified. Given the lack of constituent-specific information available in the literature, the ADEC has requested use of a factor of 1. Use of this value assumes that the concentration of sulfolane in the edible portions of the plant tissues is equivalent to the concentration of sulfolane in groundwater. To allow a direct risk comparison between this and the PPRTV Scenario, with only the toxicity criteria differing, ARCADIS has adopted this BCF for the purposes of this scenario.

After estimating the EPC, the doses of sulfolane associated with resident ingestion of homegrown fruits and vegetables were calculated using the following equation:

$$\text{Dose} = \frac{EPC_p * (IRP_{fr} + IRP_{vg}) * FI * EF * ED * CF}{BW * AT}$$

Where:

Dose = ADD (mg/kg-day)

EPC_p = EPC in produce (mg/kg) = $EPC_w * BCF$

Where:

EPC_w = EPC in water (mg/L)

BCF = water-to-produce bioconcentration factor (unitless)

IRP_{fr} = fruit ingestion rate (mg/day)

IRP_{vg} = vegetable ingestion rate (mg/day)

FI = fraction ingested (unitless)

EF = exposure frequency (days/year)

ED = exposure duration (years)

CF = conversion factor (1×10^{-6} kg/mg)

BW = body weight (kg)

AT = for the noncarcinogen sulfolane is equal to ED * 365 days per year

For the ARCADIS Comparative Scenario, the same produce consumption rates described for the PPRTV Scenario (Table 3-12) were used.

4.1.3.1.7 Ingestion of Surface Water

The doses of sulfolane associated with ingestion of surface water while swimming were calculated as follows:

$$\text{Dose} = \frac{EPC_w * ET * EF * ED * CR_w}{BW * AT}$$

Where:

Dose = ADD (mg/kg-day)

EPC_w = EPC in water (mg/L)

ET = exposure time (hours per day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

CR_w = contact rate of surface water (liters/hour)

BW = body weight (kg)

AT = for the noncarcinogen sulfolane is equal to ED * 365 days per year

For this Scenario, as shown in Table 3-12, the offsite adult and child recreational user surface-water ingestion rates of 0.071 and 0.12 liter/hour, respectively, were based on the upper percentile values for swimmers presented in the USEPA (2011a) EFH Table 3-5 representing the maximum ingestion rate for adults and the 97th percentile ingestion rate for children age 18 and under. Adult and child recreational users were assumed to swim for 30 and 6 years, respectively, for 60 days per year for 1 hour per day.

4.1.3.2 Exposure Point Concentrations

Per ADEC (2010a) guidance, "the exposure point concentration is used to assess risk and should be estimated using a 95% UCL on the mean of the contaminant concentrations." The EPC represents the average concentration of a COPC in an environmental medium that is potentially contacted by a receptor during the exposure period (USEPA 1989). The USEPA (1989) also recommends the use of the 95%

UCL as a conservative estimate of the EPC, because it represents the average concentration for which we have 95 percent confidence that the true mean concentration has not been exceeded. Unless there is site-specific evidence to the contrary, an individual receptor is assumed to be equally exposed to media within all portions of the EU during the time of the risk assessment (USEPA 2002c). For this HHRA ADEC has also requested evaluation of maximum COPC concentrations in groundwater as EPCs in the ARCADIS Comparative Scenario. Note that the ADEC Draft Risk Assessment Procedures Manual was updated during preparation of this HHRA (ADEC 2011c). The updated manual includes guidance on the use of maximum groundwater concentrations for EPCs. Because groundwater data collected from off-site wells indicate that offsite sulfolane concentrations are generally not increasing, the use of the maximum concentration will overestimate the true risk for most, actual receptors.

EPCs are estimated separately for each medium. Consistent with USEPA (2006b, 2007) guidance, surface soil, subsurface soil and groundwater EPCs were estimated using the 95% UCL of the mean for datasets with at least eight samples and at least five detected values. For this HHRA, a "dataset" was considered the aggregate of samples for one COPC, for one pathway, within a particular EU (onsite or offsite). Calculation of a 95% UCL depends on the distribution of the dataset and variability in the data. To assess statistical validity, data evaluation, distribution testing and 95% UCL calculations were performed using the USEPA's ProUCL version 4.1 (http://www.epa.gov/osp/hstl/tsc/software.htm) and according to the recommendations provided in the associated technical documentation (USEPA 2006, 2007, 2011b). Analytical data used for the HHRA are provided in Appendix A and ProUCL output files are included in Appendix B. For datasets with fewer than eight samples or fewer than five detected values, the EPC was the maximum detected concentration. Soil and groundwater datasets for most COPCs have more than eight samples each.

To combine data collected from monitoring wells and private residential wells, individual well means were calculated. The following methods were used to normalize the groundwater data in a manner that provides equal representation between wells with different numbers of observations:

- For a given well, if all samples were reported as non-detects, then the lowest detection limit associated with any sampling event at that well was used to represent the well.
- If a well had both detected concentrations and reported non-detects for a given COPC, then any non-detect was represented as one-half the detection limit associated with that sampling event for that COPC.

With the individual well means calculated as described above, ProUCL was used to estimate the 95% UCL of the mean of sulfolane across all wells in an EU (Figure 3-3). EU-1 represents approximate sulfolane concentrations in groundwater of $\geq$100 µg/L, EU-2 where detected sulfolane concentrations range from $\geq$25 to 99.9 µg/L, and EU-3 where sulfolane was from not detected above the laboratory reporting limit to 24.9 µg/L. Given the sizable area of each EU, some results included in the data analyses are different from others in each EU. For example, some non-detect results occur in EU-1 and EU-3. These values are primarily attributable to groundwater samples collected from variable screen depths. It is reasonable to assume that groundwater extracted from a variety of screen lengths may be ingested by potential receptors that might use groundwater as drinking water. Therefore, these data points were included in the EPC calculations for each EU. Non-detect observations for the COPCs in soil and groundwater were addressed using the methods described above.

In addition, per ADEC (2010a) guidance for duplicate samples, the highest detected value from the primary and duplicate samples was used to represent that sample result. For any COPC, if the 95% UCL COPC of the mean concentration exceeded the maximum detected concentration, then the maximum detected concentration was the EPC. Summary statistics for the COPCs are presented in the risk characterization, including detection frequency, number of samples, minimum and maximum detected concentrations, and calculated 95% UCL concentrations.

The same EPCs used for the PPRTV scenario (Tables 3-3 through 3-10) were used in the ARCADIS Comparative Scenario. EPCs were estimated separately for each exposure medium:

- Surface soil (0 to 2 feet bgs; see Table 3-3 for 95% UCL COPC concentrations
- Subsurface soil (0 to 15 feet bgs; see Table 3-4a for maximum COPC concentrations and Table 3-4b for 95% UCL COPC Concentrations Onsite groundwater (see Table 3-5a for maximum COPC concentrations Table 3-5b for 95% UCL COPC Concentrations
- Offsite groundwater in all wells (see Table 3-6 for maximum sulfolane concentration)
- Offsite groundwater in EU-1 (see Table 3-7 for 95% UCL sulfolane concentration)
- Offsite groundwater in EU-2 (see Table 3-8a for maximum sulfolane concentration Table 3-8b for 95% UCL sulfolane concentration)
- Offsite groundwater in EU-3 (see Table 3-9a for maximum sulfolane concentration Table 3-9b for 95% UCL sulfolane concentration)
- Offsite surface water (see Table 3-10 for maximum sulfolane concentration from pore water).

Soil, groundwater, outdoor air, indoor air, homegrown produce and surface-water EPCs are further discussed below.

4.1.3.2.1 Soil Exposure Point Concentrations

Onsite receptors may potentially contact surface soil or a combination of surface and subsurface soil. According to ADEC guidance 18 AAC 75.340(j)(2), "human exposure from ingestion, direct contact or inhalation of a volatile substance must be attained in the surface soil and the subsurface soil to a depth of at least 15 feet, unless an institutional control or site conditions prevent human exposure to the subsurface" (ADEC 2008c). Currently and in the future, FHRA will have institutional controls in place (i.e., permits) that provide worker protection (i.e., appropriate personal protective equipment) in the event of planned excavation of onsite soil. For this HHRA, two soil EPCs are calculated for each COPC. Surface soil is considered to occur from 0 to 2 feet bgs (Table 3-3) and subsurface soil is considered to occur from 0 to 15 feet bgs (Tables 3-4a and 3-4b). EPCs for soil were calculated using the 95% UCL on the mean of the dataset for surface soil exposures, or the maximum detected COPC concentrations for surface and subsurface soil exposures (relevant to potential onsite construction/trench workers).

4.1.3.2.1.1 Surface Soil Exposure Point Concentrations

For this HHRA, it is presumed that onsite commercial/industrial workers may potentially contact surface soil onsite that is not covered with pavement or vegetation. Therefore, surface soil EPCs were calculated and used to evaluate potential exposure by onsite commercial/industrial workers, using analytical data from the surface soil dataset in uncovered portions of the site (i.e., soil samples collected from ground surface to 2 feet bgs). The 95% UCL of the mean concentrations of COPCs in surface soil collected from 0 to 2 feet bgs were used to evaluate:

- Direct-contact exposure pathways to onsite outdoor commercial/industrial workers
- Potential inhalation of fugitive windborne dust from onsite surface soil by onsite outdoor commercial/ industrial workers, offsite residents and offsite outdoor commercial/industrial workers.

4.1.3.2.1.2 Surface and Subsurface Soil Exposure Point Concentrations

The 95% UCL of the mean concentrations of surface soil collected from 0 to 2 feet bgs were used to evaluate direct-contact exposure pathways to onsite outdoor commercial/industrial workers, and potential inhalation of fugitive windborne dust from onsite soil by onsite and offsite outdoor commercial/industrial workers. The onsite construction/trench worker may be directly exposed to surface and subsurface soil during excavation activities. Therefore, EPCs for evaluating exposure by the onsite construction/trench worker were generated using analytical data from the combined surface and subsurface soil dataset (i.e., soil samples collected from ground surface to as deep as 15 feet bgs). The maximum detected concentrations in the combined surface and subsurface soil sample dataset were used to estimate surface and subsurface soil EPCs for direct-contact pathways for the onsite construction/trench worker because that exposure may be localized rather than averaged over the entire site. In addition, in accordance with ADEC guidance (2010a), surface and subsurface soil EPCs based on the 95% UCLs were also used to evaluate potential exposures by the construction/trench worker.

4.1.3.2.2 Groundwater Exposure Point Concentrations

For COPCs in groundwater, COPC EPCs were distinguished for both on- and offsite potential exposures as described in the following sections.

4.1.3.2.2.1 Onsite Groundwater Exposure Point Concentrations

Groundwater EPCs were used to estimate direct-contact exposure (i.e., dermal contact) by the onsite outdoor worker and incidental ingestion and dermal contact by onsite construction/trench workers during excavation activities. Groundwater COPC EPCs based on 95% UCL concentrations were estimated using the last 2 years of data (i.e., 2009 to 2011) collected from onsite groundwater monitoring wells. In addition to evaluating the potential exposures to COPCs in groundwater over an EU using 95% UCL concentrations, the ADEC also requested that groundwater EPCs be calculated using the maximum detected concentration during the last 2 years of groundwater monitoring (see Tables 3-5a and 3-5b).

4.1.3.2.2.2 Offsite Groundwater Exposure Point Concentrations

Offsite sulfolane groundwater EPCs were used to estimate direct-contact exposure (i.e., incidental ingestion) by offsite construction/trench workers during excavation activities and to estimate direct-contact exposure (i.e., ingestion) by offsite residents and commercial/industrial receptors. In addition to evaluating the potential exposures to sulfolane in groundwater using a 95% UCL concentration for each of the EUs depicted on Figure 3-3, the ADEC also requested risk calculations using the maximum detected sulfolane concentration during the last 2 years of groundwater monitoring (i.e., 2009 to 2011), applied to the entire offsite area. EPCs for the ARCADIS Comparative Scenario were derived for each offsite EU identified on Figure 3-3 including:

- All offsite wells (Table 3-6), evaluated using the maximum offsite concentration as the EPC
- EU-1 (Table 3-7), evaluated using the 95% UCL concentration in offsite wells in EU-1
- EU-2 (Table 3-8a for maximum concentrations and Table 3-8b for 95% UCL concentrations)
- EU-3 (Table 3-9a for maximum concentrations and Table 3-9b for 95% UCL concentrations.

In summary, the maximum detected concentrations of sulfolane in offsite groundwater from EU-1, EU-2 and EU-3 were used to estimate risks and hazards for relevant receptors for the ARCADIS Comparative

Scenario. In addition, for each EU, EPCs based on the 95% UCL were also used to estimate risks and hazards for relevant receptors at each of the offsite groundwater offsite EUs (EU-1, EU-2 and EU-3), per USEPA (1989) guidance and ARCADIS professional judgment.

4.1.3.2.3 Outdoor Air Exposure Point Concentrations

In accordance with the USEPA (1989), exposure to constituents in outdoor air was evaluated as exposure to fugitive dust emissions (for non-VOCs, from soil only) or volatile emissions (for VOCs, from soil or groundwater). The USEPA (2002b) recommendations for media transfer factors to evaluate these exposures are described below.

4.1.3.2.3.1 Estimating Outdoor Air Exposure Point Concentrations from Soil Concentrations

A PEF for non-volatile COPCs was used to estimate EPCs in outdoor air from soil. The industrial PEF (1.36×10^9 m^3/kg) obtained from the Supplemental Guidance for Developing Soil Screening Levels for Contaminated Sites (USEPA 2002b) was used to estimate outdoor air EPCs of non-volatile COPCs for onsite outdoor commercial/industrial workers and construction/trench workers potentially exposed to particulate emissions from soil.

A VF for VOCs was used to estimate EPCs of volatile COPCs in outdoor air from soil (VF_{soil}). Outdoor air EPCs were estimated for the onsite outdoor commercial/industrial worker and onsite construction/trench worker using the EPC for the combined surface and subsurface soil dataset. Constituent-specific VFs_{soil} were obtained from the USEPA (2011c) RSL spreadsheets, where they exist, to estimate outdoor air EPCs of volatile COPCs for onsite outdoor commercial/industrial workers and construction/trench workers potentially exposed to volatile COPCs emanating from surface and subsurface soil. For volatile COPCs not listed in the USEPA's RSL table, VFs were derived according to USEPA guidance (USEPA 2002b). If not otherwise obtained from RSL spreadsheets, the VFs used in this assessment are shown on Table 3-11.

The following equation was used to calculate outdoor air EPCs from soil EPCs using either a PEF or VF_{soil}:

$$EPC_a = \frac{EPC_s}{PEF \text{ or } VF_{soil}}$$

Where:

EPC_a = EPC in air (mg/m^3)

EPC_s = EPC in soil (mg/kg)

PEF = particulate emission factor (m^3/kg)

VF_{soil} = volatilization factor (soil) (m^3/kg)

4.1.3.2.3.2 Estimating Outdoor Air Exposure Point Concentrations from Groundwater Concentrations

Construction workers (i.e., trench workers) may also be exposed to VOCs released from shallow groundwater that may pool in a trench and volatilize to trench air. Groundwater occurs as shallow as 8 feet bgs in portions of the site. To estimate the potential concentrations of COPCs that could volatilize from groundwater to trench air, volatilization factors (VF_{gw}) obtained from the Virginia Department of Environmental Quality (2012) were used to estimate trench air EPCs from groundwater. The trench air EPCs were used to evaluate potential exposures by on and offsite construction/trench workers potentially exposed to volatile COPCs emanating directly from shallow groundwater in an excavation trench. The equation for using VF_{gw} to calculate trench air EPCs from groundwater EPCs is as follows:

$$EPC_a = \quad EPC_{gw} \cdot VF_{gw}$$

Where:

EPC_a = EPC in trench air (mg/m^3)

EPC_{gw} = EPC in groundwater (mg/L) (see Section 4.1.3.2.2 for discussion about on and offsite groundwater EPCs)

VF_{gw} = volatilization factor (groundwater) (liter per cubic meter)

For onsite exposures, the trench air EPCs are presented in Table 3-5a (maximum EPC) and Table 3-5b (95% UCL EPC). For offsite exposures, the trench air EPCs are presented in Tables 3-6 through 3-9b.

Onsite construction/trench workers may potentially be exposed to vapors emanating from soil during trench excavation. Therefore, potential exposures to volatile EPCs in trench air from both soil and shallow groundwater sources, as well as COPCs as fugitive dust from soil were estimated for onsite construction/trench workers. For offsite construction/trench workers, sulfolane in trench air from offsite groundwater is the only potential exposure onsite.

4.1.3.2.4 Indoor Air Exposure Point Concentrations

The Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (USEPA 2002a), Vapor Intrusion Pathway: A Practical Guide (ITRC 2007a) and Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios (ITRC 2007b) were used to assess vapor intrusion. The J&E model was used to estimate indoor air concentrations resulting from intrusion of vapors from sub-slab soil gas into onsite buildings. The J&E model is a one-dimensional, screening-level model used to evaluate subsurface vapor intrusion into buildings. It incorporates both convective and diffusive mechanisms to estimate the transport of constituent vapors emanating from soil gas into indoor spaces located directly above the source (J&E 1991, USEPA 2004b). When estimating the concentration of COPC vapors in indoor air, the J&E model assumes the following:

- Constant, infinite source of constituents (e.g., in groundwater or soil gas)
- Steady-state diffusion through the unsaturated zone
- Convective and diffusive transport through the basement floor or slab
- Complete mixing within the building, estimated using an air exchange rate.

Due to the uncertainties associated with partitioning from soil to soil gas, ITRC (2007b) does not recommend using soil data as a source of COPCs to evaluate potential vapor intrusion. Therefore, source concentrations were estimated using the groundwater data as discussed in Section 2.6.2. Source concentrations for the model consisted of the groundwater EPCs based on maximum detected COPC concentrations in groundwater as well as the 95% UCL of the mean groundwater concentrations (see Section 4.1.3.2.2). Site-specific parameters, such as soil type and average soil temperature, were used in the J&E model where available. The top 3 to 5 feet of soil was assumed to be sand. Geotechnical data show that this depth interval is silty sand. An average soil temperature of 5 °C was used. The remaining parameter values, including constituent-specific parameter values, were estimated using the default values provided by the USEPA (2004b) in the User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings and the associated model spreadsheets. Appendix C presents the results of the USEPA's J&E-based model to predict indoor air COPC concentrations from COPC concentrations in onsite groundwater. For onsite exposures, the indoor air EPCs are presented in Table 3-5a (maximum EPC) and Table 3-5b (95% UCL EPC). For offsite exposures, the indoor air EPCs are presented in Tables 3-6 through 3-9b.

4.1.3.2.5 Homegrown Produce Exposure Point Concentrations

Residents who consume homegrown produce that has been irrigated with offsite groundwater were evaluated. Homegrown produce EPCs were calculated using BCFs applied to offsite groundwater EPCs (Tables 3-6 through 3-9b). The Final Results of the North Pole Garden Sampling Project (ADEC 2011b) showed that sulfolane was taken up into garden plants at concentrations below adult risk-based screening criterion developed by the ADHSS. However, a BCF equal to 1 was used predict uptake of sulfolane into both aboveground and belowground vegetables, as described in Section 3.1.3.1.6.

4.1.3.2.6 Surface-Water Exposure Point Concentrations

Recreational users who ingest surface water that has migrated from groundwater beneath the site were evaluated. The maximum detected concentration of sulfolane collected during the 2012 field season from adjacent to a frozen surface-water body was assumed to represent groundwater that has migrated offsite to downgradient water bodies. Summary statistics and the surface-water EPC are presented in Table 3-10.

4.1.3.3 Exposure Parameters

Exposure parameter values that were identified for each receptor at the site for the ARCADIS Comparative Scenario are provided in Table 3-12. The exposure parameters were identical to the exposure parameters used in the PPRTV Scenario, and were based primarily on those provided in ADEC (2010a) and USEPA (1989, 1991, 1997a and 2004a) as well as other sources, as noted. These exposure parameters meet or exceed the USEPA (1989) approach for estimating RME, which is the maximum exposure that is reasonably expected to occur in a population. Its intent is to estimate a high end exposure case (i.e., well above the average case) that is still within the range of possible exposures (USEPA 1989). Mathematically, the RME estimate for each exposure pathway combines high end values and assumptions with average values and assumptions. These assumptions tend to maximize estimates of exposure, such as choosing a value near the high end of the concentration or intake range. Therefore, the RME estimates tend to be at the high end of the exposure range, generally greater than the 90th percentile of the population.

4.1.3.4 Assessment of Potential Lead Exposures

The potential hazard associated with lead exposure was evaluated by comparing the predicted blood-lead concentrations to the CDC blood-lead threshold concentration. The threshold lead concentration is 10 µg/dL of whole blood based on potentially adverse neurological effects in children (CDC 2011). A blood-lead concentration of less than 10 µg/dL was deemed acceptable. The USEPA's (2009b) ALM model, which estimates the blood-lead levels of workers and the fetus of a pregnant worker, was used to evaluate the potential onsite exposure to lead in groundwater for the receptors evaluated.

4.2 Toxicity Assessment

The toxicity assessment identified toxicity values that relate exposure (dose) to potential risk or hazard for each COPC. Toxicity values derived from dose-response data were combined with estimates of exposure to characterize potential noncarcinogenic hazard and carcinogenic risk. Toxicity profiles were provided for risk/hazard drivers and sulfolane. Selection of toxicity values followed the hierarchies described below.

4.2.1 Noncarcinogenic Toxicity Values

Chronic and subchronic RfDs were used to evaluate potential adverse effects from ingestion, dermal and inhalation (dust) exposures to noncarcinogenic COPCs. Chronic RfDs, which correspond to 7 or more years of exposure, are specifically developed to be protective of long-term exposures to a constituent with a considerable margin of safety, which usually exceeds 1,000-fold. The USEPA (1989) defines the chronic RfD as "a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime."

As described in detail in Appendix H, ARCADIS scientifically evaluated the existing RfDs and equivalent toxicological reference values for sulfolane and derived chronic and subchronic RfDs per its best professional judgment in accordance with USEPA guidance for evaluation of primary toxicology studies (USEPA 2002d, 2003) and the derivation of RfDs (USEPA 1994, 2002e). Additional context for these decisions is provided in Appendix K. For all other COPCs, the following sources were used to identify chronic toxicological reference values:

- USEPA (2012a) IRIS.
- USEPA PPRTVs, derived by the USEPA's Superfund Health Risk Technical Support Center for the USEPA Superfund program. Current values were obtained directly from the USEPA.
- CalEPA reference exposure levels from the California OEHHA.
- ATSDR MRLs (ATSDR 2012) Chronic MRLs were used to evaluate chronic exposure.
- USEPA (1997b) HEAST.

The USEPA (1989) defines exposures lasting between 2 weeks and 7 years as subchronic exposures. As a result, the short-duration and intermittent nature of construction/trench worker and child and infant exposures require consideration of subchronic toxicity values (subchronic RfDs) to estimate the potential for effects. Subchronic RfDs are developed to be protective of subchronic exposures to constituents with a considerable measure of safety, which usually exceeds 1,000-fold (USEPA 1989). Subchronic RfDs for ingestion (oral) and inhalation (dust and vapor) exposure were identified from the following sources, in the following order of priority, for constituents other than sulfolane:

- USEPA PPRTVs. Current values were obtained directly from the USEPA.
- ATSDR MRLs (ATSDR 2012). Intermediate MRLs were used to evaluate subchronic exposure.
- USEPA (1997b) HEAST.

For the ARCADIS Comparative Scenario, subchronic RfDs, if available, were used to evaluate potential exposures to onsite construction/trench workers and offsite infants given that the period of exposure for these potential receptors is less than 7 years. If subchronic RfDs were unavailable, then only chronic RfDs were used. Despite the 6 year exposure frequency of the child offsite resident, chronic RfDs were used in the ARCADIS Comparative Scenario to evaluate potential exposures to this receptor. Refer to Section 4.5 for a discussion of uncertainties related to the use of chronic values for the child receptor.

Current USEPA guidance recommends calculating a dermal RfD by multiplying the oral RfD by the ABSGI. This recommendation requires one of the following:

- A critical study upon which the toxicity value is based employed an administered dose (e.g., delivery in diet or by gavage) in its design.

- A scientifically defensible database exists that demonstrates that the gastrointestinal absorption of the constituent in question from a medium (e.g., water, feed) similar to the one employed in the critical study is significantly less than 100 percent (e.g., less than 50 percent).

Values for ABSGI were obtained from RAGS (USEPA 2004a). Chronic and subchronic RfDs are presented in Table 3-13.

4.2.2 Carcinogenic Toxicity Values

Oral CSFs and IUR factors were used to evaluate potential carcinogenic effects from ingestion, dermal and inhalation exposures to COPCs. CSFs quantitatively describe the relationship between dose and response. A CSF represents the 95% UCL of the slope of the dose-response curve and is derived using a low-dose extrapolation procedure that assumes linearity at low doses. By applying a CSF to a particular exposure level of a potential carcinogen, the upper bound lifetime probability of an individual developing cancer related to that exposure can be estimated.

CSFs have been developed for the oral and inhalation (dust particulates) exposure routes; IURs have been developed for the inhalation exposure route. CSFs for oral and IURs for inhalation exposures were identified from the following sources, in the following descending order of priority:

- USEPA (2012a) IRIS.
- USEPA PPRTVs. Current values were obtained directly from the USEPA.
- CalEPA (2012) OEHHA Toxicity Criteria Database.
- USEPA (1997b) HEAST.

As is the case for noncarcinogenic toxicity, the USEPA has not developed dermal CSFs for use in risk assessment. Dermal CSFs were calculated in a manner similar to that of noncarcinogenic RfDs for dermal exposure by dividing the oral CSFs by the ABSGI AF (USEPA 2004a). CSFs are presented in Table 3-13.

4.2.3 Sulfolane Toxicity Values

Toxicity values for sulfolane are not presented in IRIS (USEPA 2012a). However, a PPRTV chronic oral RfD of 0.001 mg/kg-day and a PPRTV subchronic oral RfD of 0.01 mg/kg-day have been prepared for sulfolane (USEPA 2012b). The study and approach used to develop the oral RfDs were evaluated to assess potential sulfolane exposures and hazards at the site. In addition, the studies and approaches used by several other regulatory agencies to derive oral RfDs or Public Health Action Levels were evaluated.

Based on a careful and extensive review of this information, ARCADIS derived and documented the ARCADIS oral RfDs of 0.01 mg/kg-day (chronic) and 0.1 mg/kg-day (subchronic).

The ARCADIS evaluation is outlined in Appendix H with complete reference citations. As explained there, the USEPA derived a PPRTV for sulfolane using a no adverse effect level (NOAEL) approach rather than deriving a benchmark dose as has been recommended in USEPA guidance (USEPA 2000a) since 2000 and is favored in the United States for derivation of toxicological reference values for HHRA. The USEPA stated that a benchmark dose could not be derived from the sulfolane data because of a lack of "fit" of the data. The USEPA did not explain why it did not proceed to log transform the data, a step that is appropriately taken per USEPA guidance and practice. When the sulfolane data are log transformed, an excellent "fit" is obtained. Therefore, using benchmark dose modeling in this situation is preferable to using an NOAEL approach, because the model will allow the value to be informed more fully by the data and by the inferences we can reasonably draw from the data. For this and other reasons, ARCADIS disagreed with the science policy decisions made in deriving the sulfolane PPRTVs and derived alternative RfDs

Appendix H also provides the reasons why the Public Health Action Levels derived by ATSDR (2010, 2011) were not meant to be used and should not be used to derive an oral RfD for sulfolane for use in an HHRA.

In addition to evaluating sulfolane's toxicological profile, ARCADIS has considered the analysis offered by former USEPA official William Farland. Dr. Farland's credentials and scientific evaluation of sulfolane are contained in Appendix K. Dr. Farland has taken a holistic view of the available information about sulfolane and has assessed its known toxicological profile.

According to Dr. Farland, the sulfolane database has been evolving during the last three decades. Relatively speaking, compared to other industrial chemicals encountered in the environment, the available data and details of their generation are quite robust. A picture emerges of sulfolane as a minimally toxic chemical at low levels in a variety of animal test systems. The effects seen at low doses represent subtle changes that are generally considered to be of unclear toxicological significance and may represent reversible, "adaptive" responses rather than precursors to toxicity. The recent assessments have illustrated the differences in opinion and policy judgments that can arise when subtle effects with questionable toxicological significance identify points of departure for risk assessment purposes. This lack of consensus on which study to use as the "critical study" and the lack of a consistent method of assessment supports the argument that the observations in these studies provide an uncertain basis for health risk assessment and provide "screening-level values."

The assessment activities discussed above have produced a provisional health guidance value (ATSDR) and PPRTVs, including a provisional RfD (USEPA 2012b). It is important to remember that these RfD-equivalent values are not a boundary between safety and risk. A variety of uncertainties are present when extrapolating from such effects in animals to human populations and from partial lifetime studies in animals to longer term potential exposures in humans. Many of these uncertainties are inherent in the policy choices available to risk assessors and are compounded when multiple policy choices are chosen in a given assessment, such as for sulfolane.

The ARCADIS Comparative Scenario risk assessment presents estimated hazards for potential sulfolane exposures using the ARCADIS-derived oral RfDs for sulfolane (Appendices F and G).

4.2.4 Toxicity Equivalence Factors for Polynuclear Aromatic Hydrocarbons

As shown in Tables 3-2a and 3-2b, some carcinogenic PAHs have been identified as COPCs in soil. Following ADEC (2010a) guidance, TEFs were used to assess risks to carcinogenic PAHs, including benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene and indeno(1,2,3-c,d)pyrene). TEFs were applied to EPCs of all carcinogenic PAHs in surface and subsurface soil to equivalent concentrations of benzo(a)pyrene (USEPA 2011c) and total risk was derived for the carcinogenic PAH COPCs. The assessment of potential exposures to other PAHs also included PAHs identified as COPCs in soil based on analytical data collected during the 2011 field season.

4.3 Risk Characterization – ARCADIS Comparative Scenario

This section presents the ARCADIS Comparative Scenario and provides estimated ELCRs and HIs for potentially complete and significant exposure pathways identified in Section 4.1.1.4 for on- or offsite potential receptors, based on the ARCADIS-derived toxicity criteria for sulfolane and the exposure parameters presented in Table 3-12.

4.3.1 Risk Characterization

The risk characterization integrates results of the data evaluation, exposure assessment and toxicity assessment to evaluate potential risks associated with exposure to site COPCs. The basis for the risk characterization is the quantitative evaluation of potential exposure by potential receptors to COPCs, which consists of estimating carcinogenic risk and noncarcinogenic hazard. This quantitative evaluation of risk and hazard generally provides a health-protective representation of the upper end (potentially highest exposures) for a receptor. The quantitative methods used to calculate noncarcinogenic hazard and carcinogenic risk are presented below. Consistent with USEPA (1989) guidance, the potential for carcinogenic and noncarcinogenic risks were evaluated separately.

4.3.1.1 Carcinogenic Risk

For potential carcinogens, risk was estimated as the incremental probability of an individual developing cancer during a lifetime as a result of RME to a potential carcinogen and was calculated as follows:

$$ELCR = LADDi \times CSFi$$

Where:

ELCR = excess lifetime cancer risk (unitless)

LADDi = lifetime average daily dose for the *i* th constituent (mg/kg BW-day)

CSFi = cancer slope factor for the *i* th constituent (mg/kg BW-day)$^{-1}$.

The CSF converts intake averaged over a lifetime of exposure to the incremental lifetime risk of an individual developing cancer. This linear equation is only valid at low risk levels (i.e., below estimated risks of one in 100) and is an upper-bound estimate based on the 95% UCL of the slope of the dose-response curve. Therefore, the actual risk will be lower than the predicted risk. Potential risk was assumed to be additive, and risks from different possible and probable carcinogens and pathways were summed to evaluate the overall risk. Pathway-specific risks were calculated as the sum of risks from potential carcinogenic COPCs within each exposure pathway, and the total ELCR for each receptor was calculated by summing the risk estimates for the exposure pathways evaluated.

For inhalation of COPCs, the following equation from USEPA (2009a) RAGS Part F was used to assess ELCRs:

$$ELCR = LAEC * IUR$$

Where:

ELCR = excess lifetime cancer risk (unitless)

LAEC = lifetime average exposure concentration (μg/m^3)

IUR = inhalation unit risk (μg/m^3)$^{-1}$

Scientific notation was used to express potential carcinogenic risks. For example, a value of 1×10^{-6} is equal to one in 1 million (or 0.000001). The ADEC (2010a) compares individual constituent risk estimates to an acceptable cumulative ELCR of 1×10^{-5} (1 in 100,000. The acceptable cancer risk is the incremental risk attributed to the estimated upper-bound exposure (i.e., RME) to COPCs at the site. This acceptable risk is, by definition, independent of risks associated with non-site-related constituent exposures and other background cancer risks (USEPA 1989). It is standard USEPA and ADEC practice, however, to assess risks and hazards first with background constituents included and then discuss the risks in the absence of the background impacts to inform the decision makers about the risks of site-related constituents.

4.3.1.2 Noncarcinogenic Hazard

The HQ approach was used to characterize the overall potential for noncarcinogenic effects associated with exposure to multiple constituents. This approach assumes that chronic exposures to multiple constituents are additive. For direct-contact and inhalation of particulates exposures, the HQ was calculated as follows:

$$HQ = ADD / RfD$$

Where:

HQ = hazard quotient (unitless)

ADD = average daily dose (mg/kg-day)

RfD = reference dose (mg/kg-day)$^{-1}$

For inhalation of volatile COPCs, the following equation from USEPA (2009a) RAGS Part F was used to assess noncancer hazards:

$$HQ = AEC / RfC$$

Where:

HQ = hazard quotient (unitless)

AEC = average exposure concentration (μg/cm^3)

RfC = inhalation reference concentration (μg/cm^3)$^{-1}$

The HQ represents the comparison of exposure (dose) over a specified period of time to an RfD for a similar time period. The estimates of exposure (dose) were calculated based on chronic or subchronic exposures. If the HQ exceeds a value of 1, there is a possibility of adverse health effects. The magnitude of the HQ is not a mathematical prediction of the severity or incidence of the effects, but rather indicates that effects may occur. The constituent HQs were summed to calculate an HI for a pathway or site, and the USEPA (1989) recommends that the total HI for the constituents and pathways assessed not exceed a value of 1. An HI of less than 1 indicates that adverse health effects are not likely to occur from exposure to assessed constituents. HQs or HIs of greater than 1 do not indicate that significant risks are present, but rather that additional evaluation may be required to better define the level of risk.

According to the USEPA (1989), noncarcinogenic effects should be evaluated based on target organ(s) or toxicity endpoints. The USEPA believes that the assumption of dose additivity is one of the major limitations of the HI approach because it may overestimate the potential for health effects that most likely will not occur if the COPCs affect different organs or act by different mechanisms of action. The USEPA counters the potential for overestimation by specifying segregation of COPCs by effect and mechanism of action and derivation of separate HIs for each group (USEPA 1989). If the total HI exceeds a value of 1, the specific substances will be evaluated so that only substances that affect similar target organs or exhibit a similar mode of action (i.e., similar effects in the same target organs via the same mechanism) are summed. Quantitative estimates of carcinogenic risk and noncarcinogenic hazard were presented for each receptor.

4.3.1.3 Risk Characterization of Petroleum Hydrocarbon Compounds

In accordance with ADEC (2008b) Cumulative Risk Guidance, individual risks from exposure to GRO, DRO and RRO were calculated using RfDs provided by ADEC (2010a). However, these risk calculations were not included in cumulative risk estimates. Consistent with ADEC (2008b) Cumulative Risk Guidance, cumulative risks for each receptor were estimated using indicator constituents, as discussed below.

In general, quantitative risk calculated from individual petroleum constituents is considered adequate to account for risk in cumulative risk calculations from petroleum mixtures (ADEC 2008b). The key constituents of petroleum products associated with risk (e.g., PAHs, BTEX, methyl tertiary butyl ether) are included in the quantitative cumulative risk calculations and should adequately describe human health risk from exposure to site media.

4.3.2 Estimated Risks and Hazards for ARCADIS Comparative Scenario

For each total estimated ELCR and HI, the primary exposure pathway and contributing COPC(s) are indicated, as appropriate. This section presents ELCRs and HIs for potential onsite receptors (Section 4.3.2.1) and for potential offsite receptors (Section 4.3.2.2). For each potential receptor, ELCRs and/or HIs are summarized based on possible exposure to maximum and/or 95% UCL-based EPC COPC concentrations. Appendices D and E present complete risk calculations for ELCRs and HIs based on maximum (onsite construction/trench worker and recreational user exposures only) and 95% UCL COPC concentrations, respectively.

Summaries of the cumulative ELCRs and estimated HIs for the receptors evaluated under the ARCADIS Comparative Scenario are presented in the following tables:

- Tables 4-1 and 4-2 present the ELCR and HI summaries for on and offsite receptors using the maximum detected on and offsite values and the 95% UCL on and offsite values, respectively.
- Tables 4-1, 4-3a and 4-4a present ELCR and HI summaries for potential on and offsite receptors based on maximum COPC concentrations for all wells in each EU (including EU-1 because the maximum for all offsite wells is located in this EU).
- Table 4-2 presents ELCR and HI summaries for potential on and offsite receptors at EU-1 based on 95% UCL EPCs.
- Table 4-3a presents ELCR and HI summaries for offsite receptors based on maximum COPC concentrations at EU-2 wells.
- Table 4-4a presents ELCR and HI summaries for offsite receptors based on maximum COPC concentrations at EU-3 wells.

The ARCADIS Comparative scenario risk calculations are presented in Appendix D (maximum concentrations) and Appendix E (95% UCL EPCs).

The total estimated ELCRs presented in Tables 4-1 through 4-4b include arsenic as a soil COPC (arsenic was excluded as a COPC in groundwater). Based on an evaluation of arsenic in soil samples at the site, the presence of arsenic is due to background concentrations. Detected concentrations of arsenic in soil samples collected at the site are evaluated in the 2012 Revised Site Characterization Report (Barr 2012). This evaluation compared site arsenic concentrations to background studies collected in Alaska and evaluated the spatial distribution of arsenic with respect to site operations and other COPCs. The results of the evaluation concluded that the presence of arsenic in soil does not appear to be associated with refinery operations and is likely a result of background concentrations.

4.3.2.1 Estimated Risks and Hazards for Potential Onsite Receptors

Potential onsite receptors evaluated include current and future indoor and outdoor commercial workers, construction/trench workers and adult visitors. The ARCADIS-derived oral RfD was used to evaluate potential sulfolane exposures. The maximum onsite concentration of sulfolane in groundwater detected above the laboratory reporting limit between 2009 and 2011 is 10.4 mg/L. Estimated risks and hazards for the onsite receptors using maximum detected concentrations and 95% UCLs as EPCs are summarized in Table 4-1 and Table 4-2, respectively.

4.3.2.1.1 Onsite Indoor Commercial/Industrial Workers

Table D-25 (Appendix D) presents the estimated ELCRs and HIs for indoor commercial/industrial workers, based on exposures to maximum detected COPC concentrations in groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors (see Table 4-1). The total estimated ELCR is 1×10^{-5} and the total estimated HI is 0.2.

Table E-23 (Appendix E) presents the estimated ELCRs and HIs for indoor commercial/industrial workers, based on exposures to 95% UCLs of detected COPC concentrations in groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors (see Table 4-2). The total estimated ELCR is 1×10^{-6} and the total estimated HI is 0.02.

4.3.2.1.2 Onsite Outdoor Commercial/Industrial Workers

Table D-26 (Appendix D) presents the estimated ELCRs and HIs for outdoor commercial/industrial workers, assuming potential exposure to 95% UCLs of COPC concentrations in surface soil. Table D-26 also shows estimated ELCRs and HIs based on direct-contact exposures, including ingestion of, dermal contact with and inhalation of dust particles from surface soil. The total estimated ELCR is 5×10^{-6} and the total estimated HI is 0.05 (see Table 4-1). Soil ingestion contributes most to the total estimated ELCR and HIs. Arsenic is the primary risk and hazard driver. Excluding the estimated arsenic ELCR and HI, which are likely due to background, the total estimated ELCR is 2×10^{-7} and the total estimated HI is 0.03 (see Table D-26).

4.3.2.1.3 Onsite Construction/Trench Workers

The ARCADIS-derived subchronic oral RfD for sulfolane was used to estimate potential construction/ trench worker hazards in the ARCADIS Comparative Scenario. Table 4-1 and Table D-27a (Appendix D) present the estimated ELCRs and HIs for construction/trench workers based on potential exposures to maximum COPC concentrations in surface and subsurface soil, assuming direct-contact exposures including ingestion, dermal contact and inhalation of dust particles. The total estimated ELCR associated with potential exposure to COPCs in soil is 1×10^{-6} and the total estimated HI is 0.3. The soil ingestion pathway contributes most to the total soil-related estimated ELCR and HI. Excluding the estimated arsenic ELCR, which is likely based on background, the total estimated ELCR is 3×10^{-7} and the total estimated HI is 0.3.

Table 4-1 and Table D-27b (Appendix D) present ELCRs and HIs based on incidental ingestion of and dermal contact with groundwater in an onsite excavation trench, and inhalation of VOCs within trench air from groundwater based on maximum COPC concentrations in groundwater. The total estimated ELCR is 3×10^{-4} and the total estimated HI is 49. Inhalation of VOCs in the trench air is the exposure pathway that contributes most to the cumulative ELCR and HIs. Benzene, naphthalene and ethylbenzene (as estimated in trench air from groundwater) are the primary risk drivers for the total ELCR. Benzene, naphthalene, xylenes and 1,3,5-trimethylbenzene are the risk drivers for the HI.

Table 4-2 and Table E-25a (Appendix E) present the estimated ELCRs and HIs for construction/trench workers based on 95% UCL COPC concentrations and direct-contact exposures including ingestion of, dermal contact with and inhalation of dust particles in surface and subsurface soil. The total soil-related estimated ELCR is 3×10^{-7} and the total soil-related estimated HI is 0.06. Soil ingestion contributes most to the total estimated ELCR and HIs. Excluding the estimated arsenic ELCR and HI, which are likely based on background, the total estimated ELCR is 2×10^{-8} and the total estimated HI is 0.05.

Table 4-2 and Table E-25b (Appendix E) present ELCRs and HIs based on incidental ingestion of and dermal contact with groundwater in an onsite excavation trench and inhalation of VOCs within trench air from groundwater based on 95% UCL COPC concentrations. The total estimated ELCR is 3×10^{-5} and the total estimated HI is 9. Inhalation of VOCs in the trench air contributes most to ELCR and HIs. Benzene is the primary risk driver for ELCRs and benzene and naphthalene are the primary risk drivers for HIs.

4.3.2.1.4 Onsite Adult Visitors

Table 4-1 and Table D-28 (Appendix D) present the estimated ELCRs and HIs for adult visitors based on maximum COPC concentrations in onsite groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors. The total estimated ELCR is 2×10^{-7} and the total estimated HI is 0.002.

Table 4-2 and Table E-26 (Appendix E) present the estimated ELCRs and HIs for adult visitors based on 95% UCL COPC concentrations in onsite groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors. The total estimated ELCR is 1×10^{-8} and the total estimated HI is 0.0002.

4.3.2.2 *Estimated Risks and Hazards for Potential Offsite Receptors*

In the ARCADIS Comparative Scenario, potential offsite receptors evaluated include current and future residents; adults (chronic exposures), children (chronic exposures) and infants (subchronic exposures); indoor and outdoor commercial workers (chronic exposures); and construction/trench workers (subchronic exposures). The estimated risks and hazards for offsite receptors using maximum detected concentrations and 95% UCLs as EPCs are summarized in Table 4-1 and Table 4-2, respectively.

4.3.2.2.1 Offsite Adult, Child and Infant Residents

Table 4-1 and Tables D-29a and D-30a (Appendix D) present the estimated ELCRs and HIs for offsite adult and child residents, assuming potential exposure to 95% UCL COPC concentrations in ambient air from onsite surface soil (based on 95% UCL concentrations) using the ARCADIS-derived chronic oral RfD for sulfolane. The total estimated ELCRs for adult and child residents are 4×10^{-8} and 9×10^{-9}, respectively, and the total estimated HIs are both 0.001. Excluding arsenic in soil and the estimated arsenic ELCRs and HIs, which is likely due to background, the total estimated ELCRs for adult and child residents are 4×10^{-8} and 8×10^{-9}, respectively, and the total estimated HIs are both 0.0009 (see Table D-5a [Appendix D] for adult resident and Table D-6a for child resident). Table D-31a presents the estimated ELCR and HI for offsite infant residents, assuming potential exposure to 95% UCL COPC concentrations in ambient air from onsite surface soil using the USEPA (2012b) subchronic ARCADIS-derived oral RfD for sulfolane. The total estimated ELCR for infant residents is 1×10^{-9} and the total estimated HI is 0.0007. Excluding the estimated arsenic ELCR and HI, which is likely due to background, the total estimated ELCR for infant residents is 1×10^{-9} and the total estimated HI is 0.0005.

Table 4-1 and Tables D-29b, D-30b and D-31b (Appendix D) show HIs based on ingestion of the maximum detected concentration of sulfolane in groundwater (i.e., tapwater), applied across the entire offsite area (which also includes EU-1 because the maximum value occurs in this EU), for adults (chronic exposures; Table D-29b), children (chronic exposures; Table D-30b) and infants (subchronic exposures; Table D-31b), respectively. Tables D-29c, D-30c and D-31c present the HIs associated with ingestion of homegrown produce irrigated with sulfolane-impacted groundwater (maximum detected concentration) for adults (chronic exposures; Table D-29c), children (chronic exposures; Table D-30c) and infants (subchronic exposures; Table D-31c), respectively. Tables D-35 and D-36 present the HIs associated with ingestion of surface water (maximum detected concentration) for adults (chronic exposures; Table D-35) and children (chronic exposures; Table D-36).

As shown in Table 4-1 and Tables D-29b, D-30b and D-31b (Appendix D), using the ARCADIS-derived oral RfDs for sulfolane and the maximum concentration detected in offsite groundwater, the total estimated HIs associated with ingestion of groundwater are 1.2 for adult residents (chronic exposure; Table D-29b), 2.8 for child residents (chronic exposure; Table D-30b) and 0.7 for infant residents (subchronic exposure; Table D-31b), respectively, based on ingestion of tapwater. Table 4-1 and Tables D-29c, D-30c and D-31c present the total estimated HIs associated with ingestion of homegrown produce, including an HI of 0.08 for adult residents (chronic exposure; Table D-29c), 0.2 for child residents (chronic exposure; Table D-30c) and 0.03 for infant residents (subchronic exposure; Table D-31c), respectively. These HIs are based on ingestion of homegrown produce using the ARCADIS oral RfDs for sulfolane, along with the maximum detected offsite sulfolane concentration, a BCF of 1.0 and the 95th percentile *per capita* produce ingestion rates. As shown in Table 4-1 and Tables D-35 and D-36 (Appendix D), using the ARCADIS oral RfDs for sulfolane and the maximum concentration EPC, the total estimated HIs associated with ingestion of surface-water are 0.003 for adult residents (chronic exposure; Table D-35) and 0.02 for child residents (chronic exposure; Table D-36). The surface-water HIs for this receptor group are the same for each EU (Table 4-2, Table 4-3a and Table 4-4a).

Table 4-1 presents the cumulative HIs for this receptor group for all exposure pathways combined based on maximum EPCs which are 1.3 for adult residents, 3.1 for child residents (chronic exposure), and 0.7 for infant residents (subchronic exposure). Table 4-2 also presents the cumulative ELCRs for this receptor group for all exposure pathways combined based on maximum EPCs which are 4×10^{-8} for adult residents, 9×10^{-9} for child residents (chronic exposure), and 1×10^{-9} for infant residents (subchronic exposure).

Table 4-2 and Tables E-27a, E-28a and E-29a (Appendix E) present the estimated ELCRs and HIs for adults, children (chronic) and infant (subchronic) residents, respectively, based on inhalation of fugitive windborne dust or vapors from onsite COPCs in surface soil, assuming 95% UCL COPC concentrations. As shown in Table E-27a the total estimated ELCR is 4×10^{-8} and the total estimated HI is 0.001 for adult residents (chronic expo sure). For a child resident (chronic exposure), the total estimated ELCR is 9×10^{-9} and the total estimated HI is 0.001 (Table E-28a). The total estimated ELCR is 1×10^{-9} and the total estimated HI is 0.0007 for the infant resident (subchronic exposure; Table E-29a).

Assuming the 95% UCL concentration for sulfolane in EU-1, Table 4-2 and Tables E-27b, E-28b and E-29b in Appendix E) show estimated HIs based on ingestion of 95% UCL sulfolane concentrations in groundwater (i.e., tapwater) at EU-1 by resident receptors. Using the ARCADIS oral RfDs for sulfolane, the estimated HIs associated with ingestion of water are 0.5 for the adult resident (chronic exposure; Table E-27b), 1.1 for child resident (chronic exposure; Table E-28b) and 0.3 for infant resident (subchronic exposure; Table E-29b). Tables E-27c, E-28c and E-29c present the total estimated HIs associated with consumption of homegrown produce irrigated with water containing sulfolane in EU-1. The HIs are 0.03 for adult residents (chronic exposure), 0.09 for child residents (chronic exposure) and 0.01 for an infant resident (subchronic exposure), using the ARCADIS oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 4-3a and Tables D-37a, D-38b, D-39a, D-37b, D-38a and D-39b (Appendix D) present HIs based on ingestion of the maximum sulfolane concentration in groundwater (i.e., tapwater) within EU-2 for resident receptors. Using the ARCADIS oral RfDs for sulfolane, the total estimated HIs associated with ingesting tapwater containing maximum sulfolane concentrations in EU-2 are 0.4 for an adult resident (chronic exposure; Table D-37a), 0.9 for a child resident (chronic exposure; Table D-38a) and 0.2 for an infant resident (subchronic exposure; Table D-39a). In addition, Table 4-3a presents HIs associated with consumption of homegrown produce irrigated with groundwater containing the maximum sulfolane concentrations at EU-2. The estimated HIs for consumption of homegrown produce irrigated with water from EU-2 are 0.03 for an adult resident (chronic exposure; Table D-37b), 0.08 for a child resident (chronic exposure; Table D-38b) and 0.01 for an infant resident (subchronic exposure; Table D-38b), using the ARCADIS oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 4-3b and Tables E-33a, E-34a and E-35a (Appendix E) present HIs based on ingestion of the 95% UCL sulfolane concentration in groundwater (i.e., tapwater) within EU-2 for resident receptors. Using the ARCADIS oral RfDs for sulfolane, the total estimated HIs associated with ingesting tapwater containing sulfolane in EU-2 are 0.2 for an adult resident (chronic exposure; Table E-33a), 0.4 for a child resident (chronic exposure; Table E-34a) and 0.09 for an infant resident (subchronic exposure; Table E-35a). In addition, Table 4-3b and Tables E-33b, E-34b and E-35b (Appendix E) present HIs associated with consumption of homegrown produce irrigated with sulfolane-impacted groundwater at EU-2. The total estimated HIs for consumption of homegrown produce irrigated with water from EU-2 are 0.01 for an adult resident (chronic exposure; Table E-33b), 0.03 for a child resident (chronic exposure; Table E-34b) and 0.004 for an infant resident (subchronic exposure; Table E-35b) respectively, using the ARCADIS-derived oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 4-4a and Tables D-43a, D-44a and D-45a (Appendix D) show the estimated HIs based on ingestion of the maximum sulfolane concentration in groundwater (i.e., tapwater) within EU-3 by resident receptors. Using the ARCADIS oral RfDs for sulfolane, the estimated HIs associated with ingestion of tapwater are 0.2 for an adult resident (chronic exposure; Table D-43a), 0.5 for a child resident (chronic exposure; Table D-44a) and 0.1 for an infant resident (subchronic exposure; Table D-45a). In addition to a drinking water scenario, Table 4-4a and Tables D-43b, D-44b and D-45b (Appendix D) present the HIs associated with consumption of homegrown produce irrigated with the maximum detected sulfolane concentration in groundwater in EU-3. The estimated HIs for consumption of homegrown produce are 0.01 for an adult resident (chronic exposure; Table D-43b), 0.04 for a child resident (chronic exposure; Table D-44b) and 0.006 for an infant resident (subchronic exposure; Table D-45b), using the ARCADIS oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 4-4b and Tables E-39a, E-40a and E-41a (Appendix E) show the estimated HIs based on ingestion of the 95% UCL sulfolane concentration in groundwater (i.e., tapwater) within EU-3 by resident receptors. Using the ARCADIS-derived oral RfDs for sulfolane, the estimated HIs associated with ingestion of tapwater are 0.03 for an adult resident (chronic exposure; Table E-39a), 0.07 for a child resident (chronic exposure; Table E-40a) and 0.02 for an infant resident (subchronic exposure; Table E-41a). In addition to a drinking water scenario, Table 4-4b and Tables E-39b, E-40b and E-41b (Appendix E) present the HIs associated with ingestion consumption of homegrown produce irrigated with sulfolane-impacted groundwater in EU-3. The estimated HIs for consumption of homegrown produce are 0.002 for an adult resident (Table E-39b), 0.005 for a child resident (chronic exposure; Table E-40b) and 0.0007 for an infant resident (subchronic exposure; Table E-41b), using the ARCADIS oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

4.3.2.2.2 Offsite Indoor Commercial Workers

Table 4-1 and Table D-32 (Appendix D) show the HI based on ingestion of groundwater (i.e., tapwater), assuming the maximum offsite sulfolane concentration and the ARCADIS oral RfD for sulfolane. The total estimated HI is 0.9 for offsite indoor commercial/industrial workers (chronic exposure) based solely on ingestion of tapwater containing sulfolane (see Table D-32 [Appendix D]).

Table 4-2 and Table E-30 (Appendix E) show the HI based on ingestion of groundwater (i.e., tapwater), assuming the 95% UCL offsite sulfolane concentration for EU-1 and the ARCADIS oral RfD for sulfolane. The total estimated HI is 0.3 for offsite indoor commercial/industrial workers (chronic exposure) based solely on ingestion of tapwater containing sulfolane (see Table E-30 [Appendix E]).

At EU-2, two sulfolane groundwater EPCs were used to estimate potential hazards associated with ingestion of groundwater by offsite indoor commercial/industrial workers (chronic exposure). Using the maximum detected offsite sulfolane concentration at EU-2, the estimated HI is 0.3 (Table 4-3a). Comparatively, the HI based on the 95% UCL sulfolane concentration at EU-2 is 0.1. Both HIs were derived using the ARCADIS oral RfD for sulfolane (see Table D-40 [Appendix D] for maximum EPC and Table E-36 [Appendix E] for 95%UCL). Similarly, two sulfolane groundwater EPCs were used to estimate potential hazards associated with ingestion by offsite indoor commercial/industrial workers (chronic exposure) at EU-3. Table 4-4a shows the HI based on ingestion of groundwater (i.e., tapwater), assuming the maximum offsite sulfolane concentration at EU-3 and Table 4-4b shows the corresponding HI based the 95% UCL offsite sulfolane concentration at EU-3. Both HIs were derived using the ARCADIS oral RfD for sulfolane. Using the maximum detected sulfolane concentration at EU-3, the estimated HI is 0.2; the estimated HI is 0.02 for offsite indoor commercial/industrial workers (chronic exposure) based on the 95% UCL groundwater concentration at EU-3 (see Table D-46 [Appendix D] and Table E-42 [Appendix E], respectively).

4.3.2.2.3 Offsite Outdoor Commercial Workers

Table 4-1 presents the estimated ELCRs and HIs for offsite outdoor commercial workers potentially exposed via inhalation of dust particles from onsite surface soil (0 to 2 feet bgs), using 95% UCL COPC concentrations in onsite surface soil. The total estimated ELCR is 2×10^{-8} and the total estimated HI is 0.0006 (see Table D-33a [Appendix D]). Excluding the estimated arsenic concentrations in surface soil and HI, which are likely attributable to background, the total estimated ELCR is 2×10^{-8} and the total estimated HI is 0.0006 (Table D-9a). Table 4-1 also shows the HI for this receptor assuming ingestion of groundwater (i.e., tapwater) and assuming the maximum offsite sulfolane concentration. The estimated HI is 0.9 for offsite outdoor commercial/industrial workers, based on ingestion of tapwater (see Table D-33b [Appendix D]).

Table E-31a [Appendix E] shows ELCRs and HIs based on inhalation of fugitive windborne dust and vapors from onsite COPCs in surface soil, based on 95% UCL COPC concentrations and the ARCADIS oral RfD for sulfolane. It was assumed that the offsite outdoor commercial worker (chronic exposure) is located at the site boundary; therefore, the estimated ELCRs and HIs will over estimate risk for many offsite commercial worker, based on inhalation of dust and vapors from the site. As shown in Table E-31a [Appendix E], the total estimated ELCR is 2×10^{-8} and the total estimated HI is 0.0006, based on inhalation of dust and vapors in ambient air.

Assuming the 95% UCL and ARCADIS oral RfD for sulfolane in EU-1, the total estimated HI is 0.3 for offsite outdoor commercial/industrial workers (chronic exposure), based on ingestion of groundwater (see Table 4-2 and Table E-31 [Appendix E]).

At EU-2, two sulfolane groundwater EPCs were used to estimate potential hazards associated with ingestion of groundwater: the maximum detected concentration of sulfolane and the 95% UCL of the mean sulfolane concentrations. Using the maximum detected concentration in groundwater at EU-2, the estimated HI is 0.3 for offsite outdoor commercial/industrial workers (chronic exposure) based on ingestion of groundwater (see Table 4-3a and Table D-41 [Appendix D]). Using the 95% UCL sulfolane concentration, the total estimated HI is 0.1 for offsite outdoor commercial/industrial workers at EU-2, based on ingestion of tapwater (chronic exposure; see Table 4-3b and Table E-37 [Appendix E]). Both hazard estimates used the ARCADIS oral RfD for sulfolane.

Similarly, at EU-3, the 95% UCL and maximum sulfolane groundwater concentrations were both evaluated as distinct EPCs to estimate potential hazards associated with ingestion of groundwater by offsite commercial/industrial workers. Using the maximum sulfolane concentration at EU-3, the estimated HI is 0.2 (Table 4-4a and Table D-47 [Appendix D]). Using the 95% UCL sulfolane concentration, the estimated HI is 0.02 for offsite outdoor commercial/industrial workers at EU-3 (see Table 4-4b and Table E-43 [Appendix E]). Both hazard estimates are used the ARCADIS oral RfD for sulfolane.

4.3.2.2.4 Offsite Construction/Trench Workers

The estimated HIs for an offsite construction worker who is potentially exposed to maximum sulfolane concentrations by incidental ingestion of sulfolane in offsite groundwater in excavation trenches is 0.00008 (see Table 4-1 and Table D-34 [Appendix D]). This exposure is subchronic and the HI is derived assuming the maximum offsite sulfolane concentration and using the ARCADIS subchronic oral RfD for sulfolane. As discussed in Section 3.1.1.4, sulfolane is not considered to pose adverse health effects due to inhalation and dermal contact exposures. The total estimated HI is 0.00008 for offsite construction workers, based on incidental ingestion of groundwater while working in trenches.

Tables 4-2, 4-3b and 4-4b show the HIs for potential exposures by the construction worker (subchronic exposure) based on 95% UCL sulfolane concentrations for incidental ingestion of sulfolane in offsite groundwater in excavation trenches in EU-1, EU-2 and EU-3, respectively. The estimated HIs for offsite construction workers, which are based on the ARCADIS subchronic oral RfD for potential groundwater ingestion exposures of groundwater while working in trenches, and 95%UCL sulfolane concentrations, are 0.00003, 0.00001 and 0.000002 in EU-1, EU-2 and EU-3, respectively (see Tables E-32, E-38 and E-44 [Appendix E] for the hazard calculations for this receptor in EU-1, EU-2 and EU-3, respectively). Tables 4-3a and 4-4a show the corresponding HIs for this receptor group based on the maximum sulfolane groundwater concentrations at EU-2 and EU-3, respectively. The estimated HIs for offsite construction workers exposed to maximum groundwater concentrations at EU-2 and EU-3 are 0.00003 and 0.00001, respectively (see Tables D-42 and D-48 [Appendix D]).

4.3.2.2.5 Offsite Adult and Child Recreational Users

Table 4-1 and Tables D-35 and D-36 (Appendix D) show the estimated HIs for offsite adult and child (aged 1 to 6 years) recreational users (i.e., swimmer who may be exposed by incidental, ingestion of sulfolane in surface water), assuming the maximum offsite sulfolane concentration in pore water and the ARCADIS chronic oral RfD for sulfolane. The total estimated HIs are 0.003 and 0.02 for offsite adult (chronic exposure) and child recreational users (chronic exposure), respectively.

4.3.3 Conclusions for ARCADIS Comparative Scenario

Table 4-1 presents the estimated ELCRs and HIs using maximum COPC concentrations in onsite subsurface soil, maximum onsite COPC surface soil and groundwater concentrations, maximum offsite groundwater concentrations of sulfolane, and the ARCADIS oral RfDs for sulfolane. The estimated HIs are below the target HI of 1 for the onsite commercial/industrial worker, onsite commercial/industrial outdoor worker, onsite visitor, offsite indoor and outdoor commercial workers, off-site construction/trench workers, and offsite adult and child recreators. The estimated HIs exceed the target HI of 1 for onsite construction/trench workers, and offsite adult and child residents. The HI is equal to 49 for onsite construction workers based on inhalation of volatile COPCs in trench air from groundwater. Benzene, naphthalene, xylenes and 1,3,5-trimethyl benzene are the hazard drivers in the construction worker inhalation scenario. For offsite adult and child resident receptors, the HIs are equal to 1.3 and 3.1, respectively.

As shown in Table 4-2, using the 95% UCL COPC sulfolane concentrations in EU-1, the HIs and ELCRs for offsite construction workers, offsite adult and infant residents (subchronic exposure); and offsite indoor and outdoor commercial workers, and offsite recreators are below the target levels. Assuming the 95% UCL concentration for sulfolane in EU-1, the estimated HIs associated with ingestion of water is 1.1 for a child resident (chronic exposure; Table E-28b).

Table 4-3a presents the estimated ELCRs and HIs using the maximum COPC sulfolane concentrations in EU-2. Under the ARCADIS Comparative Scenario using maximum COPC concentrations in EU-2, the HIs and ELCRs for offsite construction workers, offsite adult, child (chronic exposure) and infant residents (subchronic exposure); and offsite indoor and outdoor commercial workers, and offsite recreators are below the target levels.

As shown in Table 4-3b, using the 95% UCL COPC sulfolane concentrations in EU-2, the HIs and ELCRs for offsite construction workers, offsite adult, child (chronic exposure) and infant residents (subchronic exposure); and offsite indoor and outdoor commercial workers, and offsite recreators are below the target levels.

Table 4-4a presents the estimated ELCRs and HIs using the maximum COPC sulfolane concentrations in EU-2. Under the ARCADIS Comparative Scenario using maximum COPC concentrations in EU-3, the HIs and ELCRs for offsite construction workers, offsite adult, child (chronic exposure) and infant residents (subchronic exposure); and offsite indoor and outdoor commercial workers, and offsite recreators are below the target levels.

As shown in Table 4-4b, using the 95% UCL COPC sulfolane concentrations in EU-3, the HIs and ELCRs for offsite construction workers, offsite adult, child (chronic exposure) and infant residents (subchronic exposure); and offsite indoor and outdoor commercial workers, and offsite recreators are below the target levels.

4.4 Evaluation of Potential Exposures to Lead in Onsite Groundwater

The USEPA's (2009b) ALM was used to evaluate current and future onsite outdoor commercial/industrial workers and construction/trench workers potentially exposed to lead in onsite groundwater. The maximum concentration of lead detected above the laboratory reporting limit in onsite groundwater is 2.05 µg/L. The USEPA's threshold lead concentration of 10 µg/dL of whole blood is based on potentially adverse neurological effects in children (CDC 2011). The 95th percentile PbB among fetuses of onsite adult workers, assuming potential exposure to the maximum detected concentration in onsite groundwater, was calculated using the ALM (USEPA 2009b). Using the groundwater ingestion rates and exposure frequencies for current and future onsite outdoor commercial/industrial workers and construction/trench workers presented in Table 3-12, the calculated probabilities that fetal PbBs are greater than10 µg/dL are 0.005 and 0.002%, respectively. Thus, potential exposures to lead in groundwater at the site are below the regulatory level of concern and are not expected to pose adverse health effects to current and future onsite outdoor commercial/industrial workers and construction/trench workers. The Calculations of Blood Lead Concentrations spreadsheet is provided in Appendix I.

Based on the results of the ALM (USEPA 2009b), the maximum detected concentration of lead in onsite groundwater is not expected to pose adverse health effects to current and future onsite outdoor commercial/industrial workers or construction/trench workers.

4.5 Uncertainty Assessment – ARCADIS Scenario

Each exposure parameter value and toxicity value incorporated into the HHRA is associated with some degree of uncertainty; these uncertainties may contribute to an overestimation or underestimation of risks at the site (ADEC 2011c). Therefore, key uncertainties associated with each HHRA component (i.e., data evaluation, COPC selection, toxicity assessment, exposure assessment and risk/hazard characterization) were evaluated in the following subsections. In particular, separate analyses were conducted to assess uncertainties related to oral RfDs for sulfolane, BCFs used for plant uptake of sulfolane into homegrown produce, homegrown fruit and vegetable ingestion rates, and exposure assumptions for contact with surface water. To allow a direct comparison illustrating the effect of the toxicity value selection, the ARCADIS Comparative Scenario in Section 4 has been presented with all the exposure parameters requested and approved by ADEC. For further comparison, ARCADIS also has evaluated risk for all receptors based on the ARCADIS-derived toxicity value and the exposure parameters that ARCADIS selected after its literature and data review. These results are presented in Tables4-5 through 4-9 and addressed throughout this Uncertainty Section. Wherever presented, these results are referred to as the "ARCADIS Scenario."

It is ARCADIS' expert scientific opinion that this Scenario is health protective and reflects the use of supportable science policy decisions that are consistent with USEPA guidance and current risk assessment practices.

4.5.1 Data Evaluation

Soil and onsite groundwater samples were analyzed for a large suite of constituents from multiple samples collected throughout the site over time. These samples were analyzed using accepted analytical methodologies. It is unlikely that constituents were overlooked or underestimated by the analytical methods employed. The laboratory data used for soil sulfolane analyses in 2010 and 2011 was not final at the time, but the analytical results have been validated with an approved method.

The release-related constituents detected in soil (e.g., BTEX) were measured in more than 250 soil samples, of which 88 were surface soil samples. The large data set provides high confidence in the 95% UCL on the mean concentrations and in the representativeness of the use of this statistic for EPCs.

A large number of samples of key constituents detected at the site are available for use in the data evaluation. For example, for sulfolane in offsite groundwater, more than 429 samples were grouped by concentration ranges with each range having a high number of samples to represent that zone (i.e., 105 samples in the greater than 100 µg/L EU, 72 samples in the greater than 25 µg/L EU and 252 samples in the EU with detections up to 25 µg/L). The number of samples increases the representativeness of the EPCs based on these groupings of data and it is unlikely that the EPC based on the 95% UCL on the mean concentration underestimates potential exposures to sulfolane given the number of samples. The maximum detected concentration of sulfolane (443 µg/L) is 1.4 times higher than the next highest detection of sulfolane in offsite wells and 3 times greater than the 95% UCL on the mean concentration for the greater than 100 µg/L EU. The ARCADIS Scenario presented in this Uncertainty Section evaluates potential exposures to COPCs in groundwater over each EU using 95% UCL concentrations.

Data for onsite wells with multiple sampling rounds were averaged together and these temporal average well concentrations were grouped to calculate 95% UCL concentrations on the mean. Each temporal average concentration represents multiple sampling events and provides a reliable measure of constituent concentrations in that well. Grouping the data by well to estimate EPCs reduced the number of samples upon which the statistical analysis could be based. Where too few wells were available to reliably estimate 95% UCL values, the highest temporal well average was used to represent the EPC, which is an overestimate of potential exposure.

4.5.2 Constituent of Potential Concern Selection

COPCs were selected from a list of COIs known or suspected to have been used at the site. The approaches used to characterize the site were intended to identify the COPCs in environmental media associated with current and historical site operations. Sampling events were sequentially conducted based on the knowledge obtained from past sampling events. It is likely that these events identified the majority of areas with residual COPCs. While it is possible that some substances may have been omitted, the probability of those substances being important in driving risk is expected to be low. The suite of analyses that was selected represents those constituents that would most likely result from site operations and are therefore the most relevant and appropriate constituents for estimating risks and hazards. Note that analyses of isopropanol and propylene glycol were inadvertently missed during recent groundwater sampling events. Although the potential presence of these constituents is not expected to change the outcome of the risk evaluation, these COPCs will be evaluated once data have been collected.

4.5.3 Toxicity Assessment

Dose-response values are sometimes based on limited toxicological data. For this reason, a margin of safety is built into estimates of both carcinogenic and noncarcinogenic risk, and actual risks are lower than those estimated. The two major areas of uncertainty introduced in the dose-response assessment are: (1) animal to human extrapolation and (2) high to low dose extrapolation. These are discussed below.

Human dose-response values are often extrapolated, or estimated, using the results of animal studies. Extrapolation from animals to humans introduces a great deal of uncertainty in the risk assessment because in most instances, it is not known how differently a human may react to the constituent compared to the animal species used to test the constituent. The procedures used to extrapolate from animals to humans involve conservative assumptions and incorporate several uncertainty factors that overestimate the potential adverse effects associated with a specific dose. As a result, overestimation of the potential for adverse effects to humans is more likely than underestimation.

Predicting potential health effects from exposure to media containing COPCs requires the use of models to extrapolate the observed health effects from the high doses used in laboratory studies to the anticipated human health effects from low doses experienced in the environment. The models contain conservative assumptions to account for the large degree of uncertainty associated with this extrapolation (especially for potential carcinogenic effects) and therefore, tend to be more likely to overestimate than underestimate potential risks.

Oral RfDs for sulfolane have been derived using different approaches and laboratory studies. For this Revised Draft Final HHRA, two potential chronic oral RfDs for sulfolane were used to evaluate hazards:

USEPA (2012b) PPRTV chronic oral RfD of 0.001 mg/kg-day and the ARCADIS-derived chronic oral RfD of 0.01, was derived by ARCADIS. As expected, with a lower sulfolane oral RfD value, the HIs are higher. For example, for the current and future offsite adult resident, based on ingestion of the 95% UCL concentration of sulfolane in groundwater in EU-1, the estimated HIs ranged from 5 using USEPA PPRTV chronic oral RfD of 0.001 mg/kg-day to 0.5 using the ARCADIS-derived chronic oral RfD of 0.01 mg/kg-day that was derived directly from the scientific literature. For the current and future offsite adult resident, based on ingestion of the maximum concentration of sulfolane in groundwater in EU-1, the estimated HI would be 12 using the USEPA PPRTV chronic oral RfD of 0.001 mg/kg-day and 1.2 using the ARCADIS-derived chronic oral RfD of 0.01 mg/kg-day. In addition, two potential subchronic RfDs were used to evaluate hazards associated with subchronic exposures: USEPA (2012b) PPRTV subchronic oral RfD of 0.01 mg/kg-day and the ARCADIS-derived subchronic oral RfD of 0.1 mg/kg-day, which was derived directly from the scientific literature.

For the PPRTV Scenario presented in Section 3, the USEPA PPRTV chronic oral RfD for sulfolane was used to assess potential exposures to children. In the ARCADIS Comparative Scenario presented in Section 4.3, the ARCADIS-derived chronic oral RfD for sulfolane was used to assess potential exposures to children. In the ARCADIS scenario presented in this uncertainty section, two sets of child exposures are presented: one based on the ARCADIS-derived chronic oral RfDs for sulfolane and the other based on the ARCADIS–derived chronic oral RfDs for sulfolane. The subchronic ARCADIS-derived oral RfD for sulfolane was used to assess potential exposures to children (1 to 6 yrs old) in the ARCADIS scenario because chronic RfDs correspond to 7 or more years of exposure and are developed to be protective of long-term exposures to a constituent with a considerable margin of safety, which is typically over 1,000-fold.

As noted in Dr. Farland's toxicological assessment of sulfolane provided in Appendix K, a variety of uncertainties are present when extrapolating from subtle effects in animals to human populations and from partial lifetime studies in animals to longer term potential exposures in humans. Many of these uncertainties are inherent in the policy choices available to risk assessors and are compounded when multiple policy choices are chosen in a given assessment. Risk assessments that evaluate available information and rely on scientific judgment, applied to the chemical constituent and its site-specific exposure characteristics, are typically preferred over risk assessments that make significant use of default positions.

Calculation of a "safe" drinking water level based on the policy choices incorporated for sulfolane would be up to thousands of times below the level where the subtlest potential adverse effects were NOT seen in the animal studies and even many more times below the level where these subtle effects of unknown toxicologic significance were seen. In its recent Health Consultation, the ADHSS (2012) concluded after its own evaluation that "it is unlikely that North Pole residents who drank well water with levels of sulfolane higher than ATSDR's recommended levels would experience health effects resulting from exposure to sulfolane."

4.5.4 Exposure Assessment

According to USEPA (2001) guidance, screening-level estimates of exposure and risk calculations use assumptions that maximize the estimate of risk to ensure that only those constituents that represent a *de minimis* risk are eliminated from further consideration, and those that potentially pose an unacceptable risk will be retained for consideration in subsequent steps of the risk assessment process. As requested by the ADEC, maximum concentrations of COPCs were used as EPCs in the risk calculations for the potential receptors evaluated for the PPRTV Scenario (Section 3) and the ARCADIS Comparative Scenario (Section 4.3). More often, a conservative estimate of average concentrations of constituents is used to represent EPCs (USEPA 1989, 2002c, 2006b, 2007). Potential receptors are more likely to be exposed to a range of these concentrations represented by the average or 95% UCL concentration. As such, the PPRTV Scenario and the ARCADIS Comparative Scenario also present risk results based on the 95% UCL concentrations. Because groundwater data collected from off-site wells indicate that offsite sulfolane concentrations are generally not increasing, the use of the maximum concentration will overestimate the true risk for most, actual receptors.

Concentrations of VOCs in indoor air of current and future onsite commercial/industrial structures were estimated using concentrations of VOCs in groundwater at the site. Due to the uncertainties associated with partitioning from soil to soil gas, ITRC (2007b) does not recommend using soil data as a source of COPCs to evaluate potential vapor intrusion. Thus, use of soil data to evaluate potential soil vapor concerns is inappropriate. USEPA (2002a) and ITRC (2007a) recommendations concluded that there is insufficient scientific support for this procedure. ITRC (2007a) notes "Scientific studies have failed to show good correlation between soil and soil gas sampling and analysis on a consistent basis." They conclude by recommending that soil data should be used only as a secondary line of evidence and not as a primary line. Overall, the scientific evidence indicates that use of soil data is not a reliable approach for identifying potential vapor intrusion concerns.

Dermal contact with COPCs in groundwater by current and future onsite outdoor commercial/industrial workers was considered an insignificant exposure pathway. Onsite use of groundwater beneath the site is limited to infrequent fire extinguishing. Fires at the site are very rare and the period of exposure would likely be relatively very short. Thus, exclusion of this potential exposure pathway would not significantly impact ELCR and HI estimates for these possible onsite receptors.

For the offsite CSM, it was assumed that groundwater may be connected with surface water, and pore-water data were collected to evaluate potentially complete exposure pathways for surface water. Pore-water piezometer installation methods needed to be revised for two of the three offsite locations because the surface-water body was frozen and true pore-water samples could not be collected. However, the groundwater samples collected were able to be evaluated for human health risk. Because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water

(ADHSS 2010), and given the limited groundwater- surface water interchange, the results from these samples likely overestimate the concentration of COPCs in surface water. Thus, the data used for the swimming scenario overestimate human health risk.

Ingestion of offsite groundwater by current and future offsite residents was the primary exposure pathway for these potential receptors and resulted in the relatively highest HIs, including for infants (0 to 1 year). The ingestion rate used for this age group slightly exceeded that used for children (0 to 6 years). It was also assumed that infants do not breastfeed and that their formula was made with tapwater instead of pediatrician-recommended distilled water. Thus, it is highly likely that HI estimates for this receptor were overestimated.

Only potential ingestion exposures were quantitatively assessed for sulfolane. This analysis suggests dermal contact and inhalation exposure routes are not significant for sulfolane, which is supported by ATSDR (2010 and 2011) Health Consultations and animal studies (Brown et al. 1966, Andersen et al. 1977). Although these exposure routes were excluded, inclusion of them would likely not contribute significantly to overall hazard estimates. As described in Section 4.1.1.4, dermal contact and inhalation exposure routes are not significant for sulfolane. These assumptions are based on animal studies that have shown that sulfolane is not readily absorbed through human skin because of its low permeability and is not expected to pose a significant risk via an inhalation exposure route due to its low volatility. Ingestion of sulfolane in impacted environmental media is the appropriate exposure route to assess potential hazards to on and offsite receptors. Estimated hazards based on inhalation and dermal exposure routes are insignificant relative to hazards estimated based on the ingestion exposure route.

Both the ingestion rates of homegrown fruit and vegetables and the FI of each for offsite residents are not known. In the PPRTV Scenario and the ARCADIS Comparative Scenario, ingestion of fruit and vegetables by offsite residents was evaluated based on an assumed consumption rate at a level equivalent to 95% of the population (Table 3-12). However, the USEPA (2011a) recommends use of mean homegrown produce ingestion rates because mean values from their surveys are more stable than upper percentile values and because USEPA's RME scenario is defined as a combination of high end and mean exposure assumptions (USEPA 1989, 1991). Accordingly, the ARCADIS Scenario incorporates the use of mean values.

Alternate exposure parameters used in the ARCADIS Scenario are presented on Table 4-5. This third scenario uses produce consumption parameters per USEPA guidance, which translate to adult fruit and vegetable ingestion rates of 63,000 and 175,000 mg/day, respectively; child resident fruit and vegetable ingestion rates of 69,000 and 81,000 mg/day, respectively; and infant resident fruit and vegetable ingestion rates of 41,850 and 33,750 mg/day, respectively, based on mean *per capita* intakes presented in the USEPA (2011a) EFH Table 9-3. These calculations translate into the assumption that adults will consume approximately 2.2 ounces of fruits and 6 ounces of vegetables a day; children will consume approximately 2.5 ounces of fruits and 2.9 ounce of vegetables a day; and infants will consume approximately 1.5 ounces of fruits and 1.1 ounces of vegetables a day. The risk assessment in the ARCADIS Scenario (Section 4.5.6, below) assumes that during their first year of life, infants will ingest approximately 59 pounds of homegrown fruits and vegetables. For children and adults, the produce consumption rate is assumed to be approximately 123 and 187 pounds per year of homegrown fruits and vegetables, respectively.

HIs would be approximately three times lower for the ingestion of produce exposure pathway when using the mean *per capita* ingestion rates and keeping all other assumptions the same as presented in Table 3-12. However, even using high-end exposure and uptake assumptions for ingestion of homegrown produce, this is an insignificant exposure pathway compared to ingestion of groundwater.

For the PPRTV Scenario and the ARCADIS Comparative Scenario, a groundwater-to-produce BCF value of 1 was assumed. The ARCADIS Scenario (Section 4.5.6, below) uses a lower groundwater-to-produce BCF value based on literature review and derived from data presented in the Final Results of the North Pole Garden Sampling Project (ADEC 2011b). Specifically, plant tissue concentrations were combined with measured groundwater concentrations from the corresponding drinking water wells to derive a BCF for each plant species using the following equation:

BCF = [sulfolane concentration in plant tissue from garden]/
[sulfolane concentration in water used to irrigate the garden]

Average species-specific BCF values ranged from 0.06 to 0.61, with the lower values associated with roots and vegetable fruits (e.g., tomatoes) and the higher values associated with stems and leaves. These values were further evaluated to calculate a 95% UCL value of 0.32. This BCF was used in the ARCADIS Scenario to evaluate offsite resident ingestion of homegrown produce that has been irrigated with groundwater impacted by sulfolane. Using this BCF and other exposure assumptions for the ARCADIS Scenario (Table 4-5), the HIs for the produce exposure pathway are:

- EU-1 (Table 4-7): 0.003 for adult residents (chronic exposure), 0.01 for child residents (chronic exposure) and 0.001 for infant residents (subchronic exposure).
- EU-2 (Table 4-8): 0.001 for adult residents (chronic exposure), 0.003 for child residents (chronic exposure) and 0.0004 for infant residents (subchronic exposure).
- EU-3 (Table 4-9): 0.0002 for adult residents (chronic exposure), 0.0006 for child residents (chronic exposure) and 0.00007 for infant residents (subchronic exposure).

For the ARCADIS Scenario (Section 4.5.6, below), the adult and child recreational user surface-water ingestion rates of 0.021 and 0.049 liter/hour, respectively, were based on USEPA (2011a) recommended mean values for swimmers from the EFH Table 3-5. Adult and child recreational users were assumed to swim for 30 and 6 years, respectively, for 30 days per year for 0.5 hour per day. ARCADIS chose its exposure parameters to reflect the short time during which surface-water bodies near North Pole, Alaska may be warm enough to promote swimming. As noted in Tables 4-7, 4-8, and 4-9, HIs calculated for the ARCADIS Scenario that uses the assumptions described in this paragraph are approximately ten times lower (factor of 9.7) than the ARCADIS Comparative Scenario.

4.5.5 Risk Characterization

Some HIs exceed the ADEC acceptable target HI equal to 1, particularly those estimated for onsite construction/worker exposures to volatile COPCs in the air of a trench, which have been modeled from groundwater concentrations. For this Revised Draft Final HHRA, endpoint-specific HIs were not calculated and summing all HQs regardless of endpoint is health-protective. The USEPA acknowledges that adding all HQ or HI values may overestimate hazards, because the assumption of additivity is probably appropriate only for those chemicals that exert their toxicity by the same mechanism (USEPA 1989). Application of endpoint-specific HIs is expected to reduce total HI estimates.

As noted above, the child scenario has been assessed using the chronic oral reference dose, which is by definition a daily dose that is protective for sensitive receptors for lifetime exposures. Many USEPA programs such as the drinking water program use adult scenarios to protect both adults and children. For instance, Federal drinking water standards are derived using adult receptors, and USEPA states that such standards are protective for both adults and children. The use of the child exposure levels and body weights coupled with a chronic reference dose in this section provides an additional margin of exposure, but it is uncertain whether it provides additional public health protection. Appendices and H and K provide additional information on sulfolane's toxicological profile which shows that sulfolane presents no special concerns to children and that focusing public health protection efforts on adult receptors using a chronic reference dose adequately protects children.

4.5.6 Estimated Risk and Hazards for Uncertainty Assessment - ARCADIS Scenario

This section presents a detailed summary of ELCRs and HIs for potential offsite receptors (Section 4.3.2.2) under the ARCADIS Scenario. For each potential receptor, ELCRs and/or HIs are summarized based on possible exposure to maximum soil EPC COPC concentrations and/or 95% UCL-based soil and groundwater EPC COPC concentrations. Potential ELCRs and HIs related to offsite surface water exposures are also presented in this section. Appendix G presents complete risk calculations for onsite and offsite receptors based on 95% UCL soil and groundwater COPC concentrations and maximum assumed surface water concentrations.

Summaries of the cumulative ELCRs and estimated HIs for the receptors evaluated under the ARCADIS Scenario are presented in the following tables:

- Table 4-7 presents ELCR and HI summaries for potential offsite receptors at EU-1 based on 95% UCL soil and groundwater EPCs, as well ELCR and HI summaries for potential offsite surface water exposure based on maximum pore water (assumed surface water) EPCs.

- Table 4-8 presents ELCR and HI summaries for potential offsite receptors based on 95% UCL soil EPCs and 95% UCL groundwater EPCs at EU-2 wells. ELCR and HI summaries for potential offsite surface water exposure based on maximum pore water (assumed surface water) EPCs are also presented in Table 4-8.

- Table 4-9 presents ELCR and HI summaries for potential offsite receptors based on 95% UCL soil EPCs and 95% UCL groundwater EPCs at EU-3 wells. ELCR and HI summaries for potential offsite surface water exposure based on maximum pore water (assumed surface water) EPCs are also presented in Table 4-8.

As noted above, tables 4-6 to 4-9 present ELCR and HI summaries for potential offsite receptors based on 95% UCL COPC groundwater concentrations in each of the offsite EUs (95% UCL COPC groundwater concentrations are presented in Tables 4-6 and 4-7 for EU-1, Table 4-8 for EU-2, and Table 4-9 for EU-3). Potential dust exposures from onsite surface soil are based on 95% UCL surface soil (0 to 2 feet bgs) COPC concentrations.

4.5.6.1 Estimated Risks and Hazards for Potential Offsite Resident Receptors

Potential offsite receptors evaluated in the ARCADIS Scenario include current and future residents (adults, children and infants) and off-site recreators. In these ARCADIS scenarios, potential exposures were evaluated using the ARCADIS-derived oral RfDs for sulfolane that were derived from the scientific literature. Specifically, the ARCADIS-derived chronic oral RfD for sulfolane was used to evaluate potential exposures to adult residents and adult recreational users. Both the chronic and subchronic oral RfDs for sulfolane were used to evaluate child residents and child recreational users, and only the subchronic oral RfD for sulfolane was used to evaluate infant residents exposures.

4.5.6.1.1 Offsite Adult, Child and Infant Residents

Use of the maximum detected concentration of sulfolane in groundwater is overly conservative and over estimates HIs for offsite residents (chronic exposure), as is demonstrated by available data. Evaluation of separate EU data and corresponding 95% UCL concentrations sulfolane concentrations is a more appropriate approach for the reasons discussed previously.

Table 4-7 and Tables G-5a, G-6a and G-7a (Appendix G) present the estimated ELCRs and HIs for offsite resident receptors including resident adults (chronic exposure), resident children (chronic and subchronic exposure) and resident infants (subchronic exposure), respectively, based on inhalation of soil COPCs associated with fugitive windborne dust or vapors from onsite COPCs in surface soil, assuming 95% UCL COPC concentrations. The total estimated ELCR is 4 x 10^{-8} and the total estimated HI is 0.001 for an adult resident receptor (chronic exposure; Table G-5a). The total estimated ELCR is 9 x 10^{-9} and the total estimated HI is 0.001 for child resident receptor (chronic exposure; Table G-6a). For the infant resident receptor (subchronic exposure), the total estimated ELCR is 1 x 10^{-9} and the total estimated HI is 0.0007 (Table G-7a).

For potential exposures to 95% UCL sulfolane concentrations in groundwater at EU-1, the estimated HIs for offsite residents potentially exposed via ingestion of groundwater (i.e., tapwater) from EU-1 are presented in Table 4-7. The total estimated HIs for offsite resident receptors are 0.5 for adult resident (chronic exposure; Table G-5b [Appendix G]), 1 for child resident (chronic exposure; Table G-6b [Appendix G]) and 0.3 for infant resident (subchronic exposure; Table G-7b [Appendix G]). For potential exposure to sulfolane in homegrown produce irrigated with groundwater in EU-1, the estimated HI for an adult resident is 0.003 (chronic exposure; Table G-5b [Appendix G]), the estimated HI for a child resident is 0.01 (chronic exposure; Table G-6c [Appendix G]) and the estimated HI for an infant resident is 0.001 (subchronic exposure; Table G-7c [Appendix G]). Tables G-11 and G-12 present the HIs associated with ingestion of surface water for adults (chronic exposures; Table G-11) and children (chronic exposures; Table G-12a).

Separate hazards were also evaluated for the resident child receptor based on subchronic toxicity values because the ED for this receptor (6 years) meets the definition of subchronic exposure. Table 4-7 and Table G-6d (Appendix G) presents the estimated ELCRs and HIs for offsite child residents in EU-1, assuming potential exposure to 95% UCL COPC concentrations in ambient air from onsite surface soil using subchronic RfDs, including the ARCADIS-derived subchronic oral RfD for sulfolane. The total estimated ELCR is 9 x 10^{-9} and the total estimated HI is 0.0007. Excluding the estimated arsenic ELCR and HI, which are likely attributable to background, the total estimated ELCR is 8 x 10^{-9} and the total estimated HI is 0.0005 (see Table G-6d [Appendix G]).

Table 4-7 and tables G-6e and G-6f (Appendix G) present the estimated HIs for a child resident in EU-1 based on ingestion of the 95% UCL detected concentration of sulfolane in groundwater (i.e., tapwater) and ingestion of homegrown produce, respectively. These scenarios were evaluated using the ARCADIS-derived subchronic oral RfD for sulfolane. The estimated HIs for a child resident assuming subchronic exposures at EU-1 are 0.1 and 0.001 based on ingestion of tapwater and ingestion of homegrown produce, respectively (see Tables G-6e and G-6f [Appendix G]).

Table 4-8 presents the estimated HIs associated with offsite resident receptors potentially exposed to groundwater at EU-2. Assuming the 95% UCL of sulfolane in groundwater at EU-2 and using the alternative oral RfDs for sulfolane derived directly from the scientific literature by ARCADIS, the estimated HI for an adult resident is 0.2 (chronic exposure; Table G-13a [Appendix G]), the estimated HI for a child resident is

0.4 (chronic exposure; Table G-14a [Appendix G]) and the estimated HI for an infant resident is 0.09 (subchronic exposure; Table G-15a [Appendix G]), based on ingestion of tap water. For consumption of homegrown produce irrigated with groundwater from EU-2 (95% UCL), the estimated HIs for offsite resident receptors are 0.001 for adult residents (chronic exposure; Table G-13b [Appendix G]), 0.003 for child residents (chronic exposure; Table G-14b [Appendix G]) and 0.0004 for infant residents (subchronic exposure; Table G-15b [Appendix G]).

Assuming subchronic exposures by a resident child, Table 4-8 includes the estimated HIs using the ARACADIS-derived subchronic oral RfD for sulfolane. The estimated HI is 0.04 for the offsite child resident receptor ingesting groundwater (i.e., tapwater) from ingestion of EU-2 (95% UCL concentration of sulfolane in groundwater (i.e., tapwater) (see Table G-14c [Appendix G]). The estimated HI for this receptor based on subchronic exposure and ingestion of homegrown produce irrigated with groundwater from EU-2 (95% UCL sulfolane concentration) is 0.0003 (see Table G-14d [Appendix G]).

Table 4-9 presents the hazard estimates for potential exposures by offsite resident receptors at EU-3, based on ingestion of tapwater and ingestion of homegrown produce, respectively, assuming the 95% UCL for sulfolane in groundwater and ARCADIS-derived oral RfD for sulfolane. For offsite resident receptors ingesting groundwater (i.e., tapwater), the estimated HIs are 0.03 for the adult resident (chronic exposure; Table G-19a [Appendix G]), 0.07 for the child resident (chronic exposures; Table G-20a [Appendix G]) and 0.02 for the infant resident (subchronic exposures; Table G-21a [Appendix G]). For potential exposures from consumption of homegrown produce in EU-3, the estimated HIs are 0.0002 for the adult resident (chronic exposure; Table G-19b [Appendix G]), 0.0006 for the child resident (chronic exposures; see Table G-20b [Appendix G]) and 0.00007 for the infant resident (subchronic exposures; Table G-21b [Appendix G]).

Assuming subchronic exposures by a resident child, Table 4-9 includes the estimated HIs using the alternative subchronic oral RfD for sulfolane. The estimated HI is 0.007 for the offsite child resident receptor ingesting groundwater (i.e., tapwater) from EU-3 (95% UCL concentration of sulfolane) (Table G-20c [Appendix G]). The estimated HI is 0.00006 for this receptor based on subchronic ingestion of homegrown produce irrigated with groundwater from EU-3 (95% UCL sulfolane concentration) (see Table G-20d [Appendix G]).

4.5.6.1.2 Offsite Adult and Child Recreational Users

The estimated HIs for an offsite adult recreational user (i.e., swimmer) who may incidentally ingest sulfolane in surface water are presented in Table 4-7, 4-8, and 4-9. The estimated HIs are based on the maximum offsite sulfolane concentration in pore water and the ARCADIS-derived chronic oral RfDs for sulfolane. For offsite adult recreational users, the estimated HI is 0.0002 (chronic exposure; Table G-11 [Appendix G]). Tables 4-7, 4-8, and 4-9 also show the estimated HIs for the offsite child (aged 1 to 6 years) recreational user (i.e., swimmer) who may incidentally ingest sulfolane in surface water, assuming the maximum offsite sulfolane concentration in pore water and using both the ARCADIS-derived chronic and subchronic oral RfDs for sulfolane, respectively. For offsite child recreational users, the HI is 0.002 assuming chronic exposure (Table G-12a [Appendix G]) and 0.0002 assuming subchronic exposures (Table G-12b [Appendix G]).

4.5.7 Conclusions for ARCADIS Scenario

Table 4-7 presents the estimated ELCRs and HIs using 95% UCL COPC concentrations in EU-1. Using the 95% UCL onsite COPC soil concentrations, the 95% UCL onsite and EU-1 offsite sulfolane groundwater concentrations, the ARCADIS-derived oral RfDs for sulfolane, and the alternate ARCADIS exposure assumptions (Table 4-5), the estimated HIs for all receptors evaluated in the ARCADIS Scenario are equal to or below the target HI of 1.

The estimated total ELCRs for the potential receptors evaluated in the ARCADIS Scenario are equal to or below the ADEC acceptable ELCR of 1×10^{-5}.

As shown in Table 4-8, using the 95% UCL COPC concentrations in onsite surface soil and 95% UCL sulfolane concentration in groundwater in EU-2, the estimated HIs are below the target HI of 1 for the potential receptors evaluated. The estimated total ELCRs for the receptors evaluated are below the ADEC acceptable ELCR of 1×10^{-5}.

As shown in Table 4-9, using the 95% UCL COPC concentrations in onsite surface soil and 95% UCL sulfolane concentration in groundwater in EU-3, the estimated HIs are below the target HI of 1 for the potential receptors evaluated. The estimated total ELCRs for the receptors evaluated are below the ADEC acceptable ELCR of 1×10^{-5}.

As demonstrated in this section and in Tables 4-6 through 4-9, there are no offsite potential receptors that exceed the target HI of 1 and no offsite EUs that exceed the acceptable ELCR when the ARCADIS-derived toxicity value is used in combination with the ARCADIS exposure parameters.

5. Site-Specific Alternative Cleanup Levels

The Draft Risk Assessment Procedures Manual (ADEC 2010a, 2011d) provides for ACLs to be calculated for receptors who exceed a target risk level, by setting the total carcinogenic risk to 1×10^{-5} or the HI to 1 and solving for the concentration term for each COPC in each medium that contributes significantly to total potential risk ("risk drivers"). Under this method, using the exposure parameters set forth in the PPRTV and ARCADIS Comparative Scenarios, and individual COPC ELCR target risk of 1×10^{-5} and HI of 1, ACLs of 0.6, 0.03, 3.5 and 0.09 mg/L were calculated for benzene, naphthalene, xylenes and 1,3,5-trimethylbenzene, respectively, based on incidental ingestion of groundwater in a trench, dermal contact with groundwater and inhalation of trench air by onsite construction workers. Table 5-1 presents the ACLs for the PPRTV, ARCADIS Comparative, and ARCADIS Scenarios, Appendix J provides the calculations.

The ADEC and FHRA continue to discuss and evaluate an appropriate ACL for sulfolane; therefore, no ACL is proposed for sulfolane at this time. Using the various exposure scenarios, toxicological reference values and exposure assumptions presented in this Revised Draft Final HHRA, the range of potential ACLs includes:

- 14 µg/L, derived from the PPRTV RfD and ADEC-approved exposure assumptions (PPRTV Scenario), for a child with chronic exposure
- 145 µg/L, derived from the ARCADIS RfD and ADEC-approved exposure assumptions (ARCADIS Comparative Scenario), for a child with chronic exposure
- 362 µg/L, derived from the ARCADIS RfD and the alternate exposure assumptions (ARCADIS Scenario), for an adult with chronic exposure.

Based on the Margin of Exposure evaluation presented in Appendix K, ARCADIS and Dr. Farland conclude that an ACL within this range would be protective of human health. Table 5-2 provides the ACLs that correspond to the PPRTV, ARCADIS Comparative, and ARCADIS Scenarios for infant (subchronic), child (subchronic and chronic) and adult (chronic) exposures.

In the meantime, as potential sulfolane ACLs are considered, offsite residents and commercial workers located immediately north of the site obtain drinking water from the city's new water supply wells. Individuals located outside the city water service area but within or near the dissolved sulfolane plume have been provided with alternative water supplies by FHRA (including treatment systems, bulk water tanks or continued supplies of bottled water) to eliminate potential ingestion of groundwater impacted with sulfolane.

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